PHYSICAL PROPERTIES OF MUSTARD SEEDS AS AFFECTED BY CRACKING TREATMENTS

By

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TREATMENTS

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CHAPTER I

INTRODUCTION

Mustard is manufactured in the United States from seed grown in the northern states and Canada. The value of prepared condiment mustard consumed in this country is about 300 million dollars, half of which is sold to food service and half through grocery stores (Supermarket Sales Manual, 1990). Processing is done by a few large national companies and numerous smaller ones which distribute their products locally.

Processing of condiment mustard, with slight variations between manufacturers, basically includes two stages of seed size reduction, i.e., initial cracking and final grinding. One commonly used method consists of dry cracking whole mustard seed through a hammer mill or roller mill, mixing it with liquid and solid ingredients, and grinding with a stone mill to a very fine texture.

Condiment mustard, as a kind of semi-solid food of plant origin, is a suspension or dispersion of particles in an aqueous medium, with approximately 17% mustard seed. So, in addition to its flavor, the texture also influences consumer acceptance.

The texture of prepared mustard is affected by the particle size distribution of the product. Kokini et al. (1977) found that thickness or flowability is the most important single descriptor of processed mustard texture. This flowability can be described by a model that accounts for the viscoelastic behavior of food materials

(Dickie and Kokini, 1983). This property, as well as many other rheological properties, is greatly affected by particle size distribution (Jeffrey and Acrivos, 1976). A further understanding of the rheological behavior of processed mustard as a function of particle size distribution was obtained (Aguilar et al., 1991a, 1991b) to predict the flow properties, quality, texture, and physical stability during storage.

The particle size of processed mustard also affects its stability during storage. When colloidal particles are dispersed in a liquid medium, attractive and repulsive forces between particles are generated. As the emulsions age, the attractive forces produce adherence of the particles in the dispersed phase and, therefore, a gradual growth in particle size. Eventually, the particles become sufficiently large to produce separation. This increase in particle size of food emulsions during aging depends on many variables, including the initial particle size of the dispersed phase (Aguilar et al., 1991b). Control of the rheological properties of processed mustard by manipulation of particle size distribution during processing may improve the control of the storage time and temperature dependent aggregation process of colloidal particles, and, therefore, reduce liquid separation from the semi-solid matrix.

Particle size reduction is a critical step in determining the textural quality of the finished mustard product. In addition, an investigation of mustard manufacturing shows that not only the final grinding operation, but also the initial cracking operation affect the texture of the final product. To date all studies have concentrated on the final product. It is not yet possible to ensure the final product's quality by controlling each size-reduction step in the manufacturing process. The final quality is attained by trial-and-error over years of experience. The process is commonly performed in batches (usually a batch of 1800-2700 kg), and if a batch does not meet the required specifications, it will be used for lower quality products or many have to be entirely discarded. Therefore, from the initial cracking stage, control of each step in the operation is necessary to ensure the quality of the final product.

Another consideration for better control of the initial cracking, although of less importance at this time to food processing companies, is the energy consumed during the entire process, since milling is the major energy user during mustard preparation. Energy necessary for size reduction of particles is proportional to the surface area increase (Dallavalle, 1948), i.e., proportional to the increase of "diameter" squared. For a multiple stage size-reduction system, there is an optimum condition for the degree of size reduction in each stage that minimizes the total energy consumption. Therefore, improved understanding and control of the initial cracking operation is indispensable for energy management in mustard processing.

This research is focused on the initial milling operation used in dry cracking of mustard, with the objective to determine the changes in the physical properties of mustard seed, (such as particle size distribution, bulk density, bulk compressibility, and back extrusion force) as affected by the following milling parameters:

(a) mill type (hammer or roller),

(b) gap between rolls of the roller mill,

(c) feed rate through the hammer mill, and

(d) seed temperature at the time of cracking.

CHAPTER II

LITERATURE REVIEW

Prepared Mustard

The texture of condiment mustard, as a semi-solid food, has been studied in recent years because of its importance to consumer's acceptability of the product. Studies were performed from different standpoints and by a variety of approaches with a focus on the properties of the final product.

Canovas and Peleg (1983) evaluated the rheological characteristics of commercial mustard emulsions, as well as some other semi-solid foods, by two successive shearing cycles in a coaxial viscometer and found that the Herschel-Bulkley and the modified Casson equations were equally good mathematical representations of the experimental flow curves at shear rates of 10 to 100 sec^{-1}, especially after the sample had already been sheared once. Dervisoglu and Kokini (1986) confirmed that at the high shear rate range of (1 to 1600 sec^{-1}), Gulden's mustard and other semi-solid foods could be best described as a Herschel-Bulkley material, which also had the best fit of average velocity data in pipe flow. In the low shear rate range (0.05 to 1.0 sec^{-1}), rheological behavior was best modeled as a Bingham plastic.

Dickie and Kokini (1983) proposed a way to evaluate food thickness. They determined the subjective thickness of 15 semi-solid foods including Gulden's mustard by correlating the rheological parameters obtained from a Rheometries mechanical spectrometer with the qualitative indication of shear rate in the human mouth. Their final result provided a design equation for the "thickness" of foods from a rheological standpoint.

Aguilar et al. (1991a) reported that the rheological behavior of processed mustard was largely determined by the larger size particles. Increases in the percentage of larger size particles produced higher apparent viscosity of nonmixed samples, Bingham yield stress, plastic apparent viscosity, shear stress constant and coefficient of thixotropic breakdown from the Weltman stress decay model, the yield stress and consistency index from the Herschel-Bulkley model, and the storage and loss moduli. Control of the rheological properties of processed yellow mustard could be obtained by manipulation of particle size distribution during processing. Their investigation of the size distribution of processed yellow mustard after stone milling showed that, on a population basis (i.e., particle number basis), all samples had unimodel size distributions with little difference among the samples, and therefore population based particle size distribution could not be used to distinguish among the different milling treatments. On a particle volume basis, all the milling treatments had well-defined bimodal distributions consisting of two quasi-normal distributions. The small-size particles were similar among the three milling treatments, while the large-size group varied among treatments. The coarser the milling, the higher the larger-size mode for volume based particle distribution. The most important particle size index in relating milling treatment to rheological behavior was not the population mode but the larger-size mode from the bimodal particle volume distribution. The stone milling treatments were obtained by adjusting the stone clearance, the flow rate, and the sample temperature.

Aguilar et al. (1991b) also found that the rheological behavior and population-based particle size distribution of processed mustard were significantly affected by storage time and temperature. After 3-month storage at 45 °C, all samples showed visible liquid separation and significant aggregation of colloidal particles, with an increase in the population mode and a decrease in the colloidal population (% colloids) from the population-based size distribution. The fine-milled samples were susceptible to aggregation, exhibiting significant liquid separation and an increase in population mode after 3-month storage at 25 °C. The volume-based bimodal distribution did not change as a result of aggregation. It was believed that control of storage time and temperature-dependent aggregation process of colloidal particles, or the reduction of liquid separation from the semi-solid matrix of processed mustard could be achieved by manipulation of the particle size distribution during processing.

Canovas and Peleg (1983) found that the effects of time and shear on the flow curve features varied considerably, not only among different types of products, but also among the same products of different brands.

Particle Size Reduction and Determination

For semi-solid foods of plant origin such as condiment mustard, size reduction is a common processing operation. The three commonly used mills for particle size reduction in the food industry are hammer mill, roller mill, and stone mill. The stone mill is mainly used for fine grinding, and the other two for coarse cracking of the grain. The investigation of grain sorghum and corn grinding (Martin, 1985) showed that a roller mill was more efficient (i.e., higher coarse weight produced per unit energy) but produced particles larger than the hammer mill. According to Appel (1986), a hammer milled particle has a smaller surface area per unit weight and higher bulk density than a roller milled particle, for particles in the same sieve size range.

Because of the effect of particle size on rheological properties, particle size determination is a key to predicting the flow properties, quality, texture, and physical stability of semi-solid food. Schubert (1987) illustrated some important aspects of particle technology in food engineering. For particle size analysis, he suggested that the following methods are suitable for foods:

(a) analysis of photographic images including scanning electron micrographs,

(b) dry and wet sieving,

(c) electrical impedance of particles, and

(d) evaluation of laser diffraction patterns.

Because of the extensive effort taken in sample preparation, method (a) is time-consuming despite automatic processing of the image. Method (b) is also time-consuming, but indispensable for many purposes including quality control. Methods (c) and (d) are rapid by using automatic measuring equipment suitable for on-line measurements. Schubert also described some other properties of individual particles and of particulate systems and particle characteristics, such as particle adhesion, porosity, bulk density, and flow properties of powders.

Back Extrusion Test

The rheological properties of fluid or semi-solid foods are key parameters required to solve the following food industry problems: quality control, evaluation of consumer acceptance or texture, process design and control, elucidation of food structure, and composition. Back extrusion can be a very useful tool in solving food rheology problems. After reviewing methods of determining properties of non-thixotropic fluids, Steffe and Osorio (1987) presented this new technique for quantifying the behavior of thixotropic fluids. The short time and low cost required to conduct the test make it a good technique for quality control in product development. A back extrusion test requires only simple and readily available equipment, i.e., rods, test tubes or graduated cylinders, and a compression testing machine. Loading problems are minimized in the analysis of time-dependent materials. Flushing effects may reduce sedimentation problems, and yield stresses can be easily determined. Back extrusion offers some unique possibilities which have not been fully exploited. It may also be very useful in studying thick pastes and dough, because very high forces required to create flow can be generated, which is often very difficult with conventional viscometers.

Osorio and Steffe (1987) developed a mathematical model to describe the behavior of power law fluids in a back extrusion device and obtained the expressions to calculate shear stress and shear rate at the plunger wall.

Bourne and Moyer (1968) developed the methodology for using the back extrusion technique to measure the texture of fresh peas by investigating the effects of annulus width, plunger speed, sample size, and the presence of water. The maximum force required to accomplish back extrusion was measured and used as an index of textural quality of the peas. The test was insensitive to sample size, the presence of water in the sample, and the plunger speed in the range of 20 to 50 cm/min. They believe that this test would be used as a routine commercial testing instrument because of its simplicity in construction and operation and its comparatively low cost.

Anzaldua-Morales and Brennan (1982) used back extrusion, compression, shearing, and a puncture tests to relate the textural characteristics of baked beans to the mechanical properties of the field-dried beans. For canned beans in a brine, the maximum compression force and back extrusion force were linearly dependent on the maximum compression force of the dry beans, while in the case of beans canned in tomato sauce, only the back extrusion force exhibited linear dependence. The back extrusion force was correlated with sensory firmness and the energy for back extrusion with sensory chewiness.

Cagampang et al. (1984) evaluated the back extrusion technique for measuring the difference in texture between boiled undecorticated and decorticated sorghum differing in their vitreousness. They reported that a small sample (10 g) back extrusion test could be considered as a sensitive indirect measure of the texture of boiled sorghum. The test had several advantages: (1) it required only a small amount of sample, (2) it used a test cell which was inexpensive and easy to clean, and (3) it involved simple sample preparation.

Reyes and Jindal (1990) used small sample back extrusion to measure the textural change of rice due to different degrees of cooking. Texture parameters determined from a back extrusion test were more sensitive and reproducible than the hardness and stickiness measurements based on the single-kernel method.

Alviar and Reid (1990) reported that the back extrusion technique is a very useful tool in assessing the rheological behavior of non-Newtonian fluids such as tomato concentrates. For consistency determinations, it is a good alternative to more sophisticated instruments, such as the Carri-Med rheometer.

Gandhi and Bourne (1991) applied the back extrusion technique to the softness test of cooked soybeans and determined the effect of soaking and cooking time on the rate of thermal softening of soybeans.

CHAPTER III

METHODS AND PROCEDURE

Two mills were used to crack whole mustard seed; an H.C. Davis Model 50 roller mill with two 23x15-cm diameter corrugated rolls and a well-used commercial W.W. Model K33L hammer mill with a 46-cm wide screen having 3.2-mm round openings. The two rolls of the roller mill have hooked corrugations with 5 cuts per cm of circumference and run at the same speed. The gap between the rolls, which was the critical factor in controlling the particle size, was adjustable down to 0.2 mm. By changing the opening of the hammer mill's gravity feed slide gate, the feed rate could be adjusted from 17 to 29 kg/min. The roller mill was located in the Agricultural Engineering Laboratory of Oklahoma State University and the hammer mill at Clements Food Co. in Oklahoma City.

Preliminary experiments with the roller mill were conducted to determine which parameters in the primary cracking operation have a measurable effect on the cracked seed properties and should therefore be included as independent variables. The parameters tested were: seed temperature, gap between the rolls of the roller mill, and the feed rate of the roller mill. A U.S. Standard Sieve #10 was used to separate fine particles from coarse ones. These preliminary experiments were performed to determine if changes in operational parameters and input seed condition would produce the changes in the fine-to-coarse ratio. The practical ranges for the operational parameters selected for testing are shown in Table I. Seed temperature and roll gap had significant effects on the fine-to-coarse ratio, while feed rate did not. Little was known about the seed temperature effect, and therefore more temperature levels were selected to determine the proper experiment condition. Figure 1 shows that, when other conditions were the same, significantly more fine particles were produced from colder seed. As seed temperature was decreased from 18 °C to 14 °C, the proportion of fine particles increased most significantly. In this temperature

TABLE I

PRELIMINARY ROLLER MILL TESTS

Operational Parameters	Parameter Value	Ratio of f.w./c.w.*
Seed temperature (°C) at a fixed 0.4-mm roll gap	2	2.81
	8	2.54
	14	2.25
	16	1.83
	18	1.21
	25	1.03
	33	0.85
Roll gap (mm) at 16 °C seed temp.	0.4	1.83
	0.8	0.93
Feed rate (kg/min)	0.4	1.048
	1.7	1.044

* the weight ratio of fine particles to coarse particles, or the ratio of the weight of particles passing through sieve #10 to that retained on it.

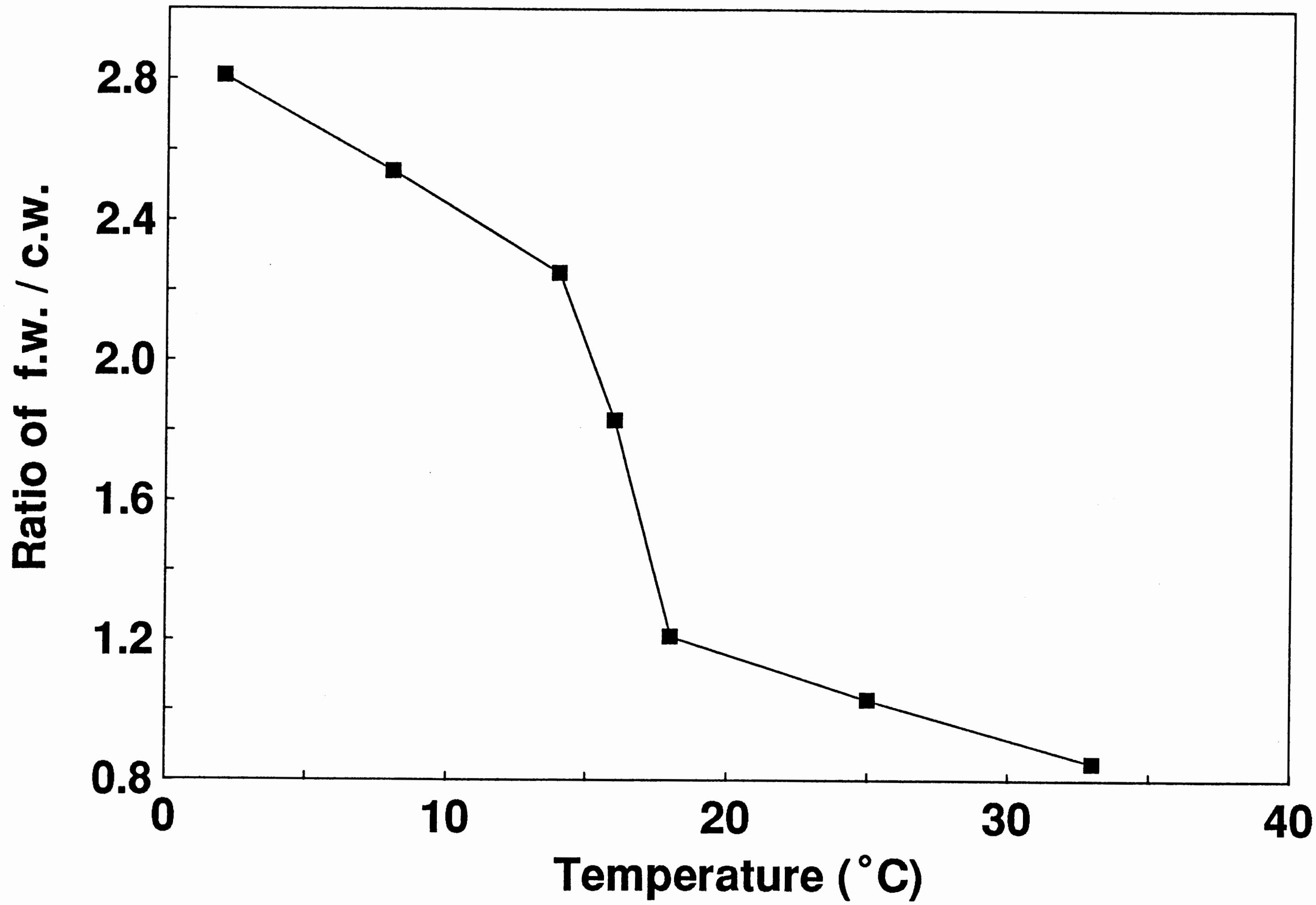

Figure 1. Temperature Effect on Fine-to-Coarse Ratio for Roller Milling (roll gap: 0.4 mm)

range, the change of the fine-to-coarse ratio was 0.26/°C, while at temperatures of 3 °C to 18 °C and at 14 °C to 2 °C, the rates were 0.024 and 0.047/°C, respectively. Thus, temperatures from 14 to 18 °C were avoided in the main experiment.

Only two hammer milled samples were available; those cracked during a 29-kg/min feed rate and those cracked during a 17-kg/min feed rate. The seed temperature of both samples was about 20 °C when cracking. A significant difference in particle size between the two samples was readily apparent.

Thus, seed temperature and roll gap for the roller mill and feed rate for hammer mill were considered as the independent variables for the main experiment. A 3x3 complete factorial experiment was constructed for the roller mill, plus two treatments for the hammer mill, making a total of 11 treatments as shown in Table II.

The preliminary tests showed that, when cracked, the particle shape changed from approximately spherical to various other shapes. Non-spherical particles require more than one parameter to indicate their size. A mixture of particle sizes and shapes requires additional parameters to properly describe the mass average particle size. We selected four relatively simple techniques; particle size distribution by sieving, bulk density, bulk compressibility, and back extrusion force. Sieving particle size distribution provided a nominal size distribution. The other three bulk properties involved an index of particle shape as well as particle size. Although these tests were not all-inclusive, they were relatively easy and quick to perform, required minimal equipment, and were commonly used standard methods. For the measurement of each of these 4 dependent parameters, 6 to 10 replications were taken from each of the 11 treatments. Samples were randomly taken from the whole population of the cracked

TABLE II

CRACKING TREATMENTS FOR MAIN EXPERIMENT

	Roll Gap (mm):	Seed Cracking Temperature (°C):
Roller Mill	0.3	5
		20
		35
	0.5	5
		20
		35
	0.7	5
		20
		35
		Feed Rate (kg/min):
Hammer Mill		17
		29

seed processed by that treatment condition.

Material Preparation

The samples were prepared by cracking the cleaned commercial whole yellow mustard seed through the roller mill or the hammer mill using the desired operational condition. In preparing the seed of the desired temperatures for the roller mill treatments, two kg of whole seeds were placed into each of the 45 air-tight plastic bags and were randomly placed into three environmental chambers with the temperatures of 5, 20, or 35 °C. The seeds were left in the chambers for at least 24 hours to allow the seed temperature to reach the chamber temperature. For milling, five bags of seeds were randomly selected from each chamber and cracked at one of the three gap settings, i.e., 0.3, 0.5, and 0.7 mm, with a constant feed rate of 0.9 kg/min. The seed moisture content when cracked was 12.9 %, which was measured by standard oven method (ASAE, 1989). In this way, 10 kg of seed were prepared for each of the 9 roller mill treatments. The hammer mill cracking was done during the regular production at Clements Food Co., without pre-conditioning the seed.

Dependent Variable Measurement

Bulk Density

A one-quart standard grain weight-per-bushel tester was used to measure the bulk density of cracked mustard. The container was filled to overflowing with the sample and struck off level on top. Then, the sample was weighed, and the reading was converted to bulk density knowing the volume of the container.

Bulk density is affected by porosity as well as the solid density of the particle and can be described by the formula:

$$\rho_b=(1-\varepsilon)\rho_s$$

Where ε, the porosity, is a function of particle shape, size, and arrangement, and ρ_s is the solid density of the particle.

Provided all samples were loaded in the same way, differences in bulk density among the mustard particles from different treatments should indicate the differences in both particle shape and particle size.

Bulk Compressibility

The force needed to compress a loosely packed sample a predetermined distance was used as an indicator of the bulk compressibility of the sample. A large force indicates small compressibility of the sample. Bulk compressibility was considered as an indicator combining both particle size and particle shape when samples were packed in a consistent manner. The sample was loosely filled to overflowing into a cylindrical thick-walled metal cell with internal dimensions of 57 mm in diameter and 75 mm in height and was struck level on top. Then, the filled cell was placed in an Instron universal testing machine and compressed by a cylindrical plunger with an outside diameter of 56 mm traveling at 100 mm/min. The amount of compression was determined through preliminary tests by two considerations; it should show the most difference among samples, and it should produce minimal compression of the individual seeds.

Differences between treatments were most significant for large volume reductions, while too much compression would involve both bulk plus solid compression. The volume reduction ratio chosen was 0.2, which corresponded to a vertical compression distance of 15 mm (i.e., 15/75=0.2). During the preliminary test, samples from all 11 treatments were compressed to the testing machine's maximum force (500 kg), and the force vs. deformation relationships were recorded on graphs. For each force vs. deformation curve, the starting point for the linear portion and the maximum effective compressing distance were marked. The smallest of these distances, about 15 mm, dictated the 0.2 volume reduction ratio.

Back Extrusion Force

Back extrusion consists of compressing a slurry in a thick-walled cylindrical cell with a loosely-fitting plunger until the sample flows up through the annulus between the plunger and the cell wall. The resulting plunger force vs. distance curve is shown in Figure 2. In the first nonlinear region (A-B), particles are packed more and more tightly into the diminishing space available. At point B the particles are packed solidly, and liquid begins to be pressed from the particles and interstices. The approximately linear portion from B to C represents the compression of the sample. The slope is related to the apparent elastic properties of the sample, and can be an index of firmness. At point C, the force is sufficient to make particles flow up through the annulus. This force is an index of cohesiveness (J. DeMan et al., 1976). Extrusion continues (C-D) with a generally constant force by three mechanisms postulated to be shear, compression, and extrusion. Parameters that can be derived from the force-displacement curve are the first peak extrusion force, average extrusion force, total work done, weight of material extruded, and extrusion time (Bourne and Moyer, 1968).

The ideal shape of the back extrusion curve shown in Figure 2 is not necessarily obtained through all size combinations of cells and plungers. Preliminary

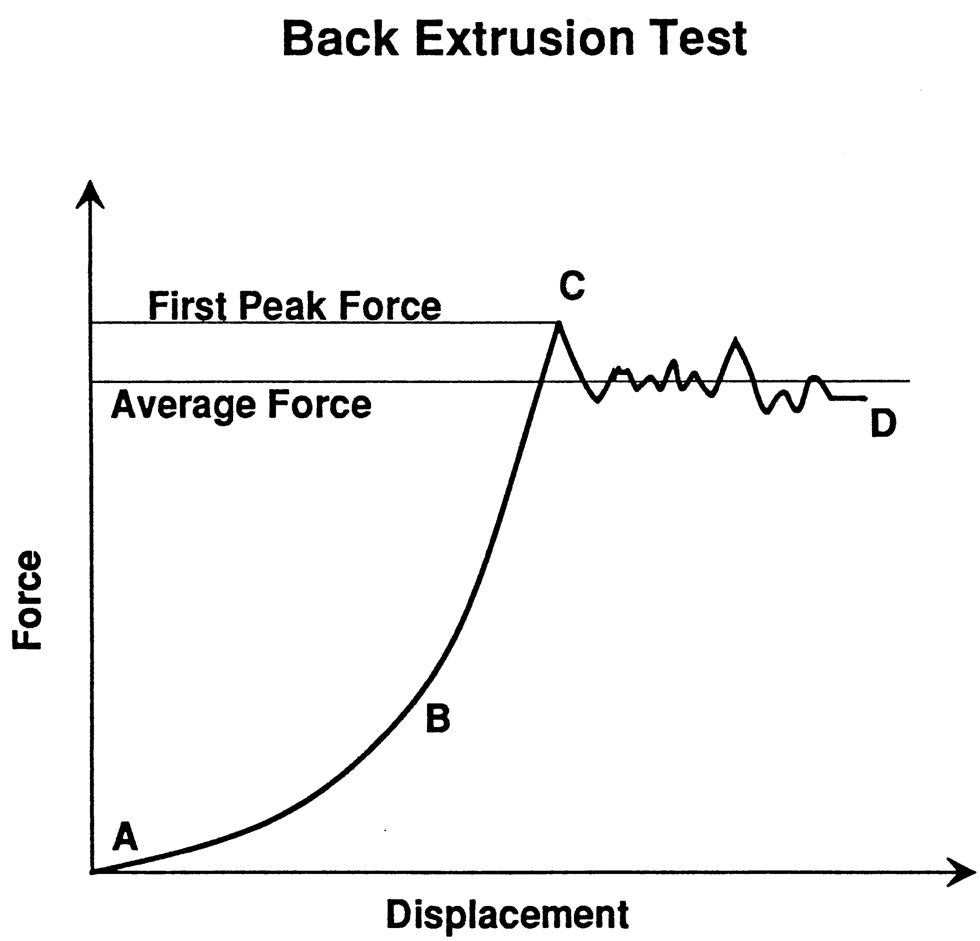

Figure 2. Typical Force-Displacement Curve from Back Extrusion Test

experiments were conducted to find the proper combination, through which the typical plateau-shaped curve can be obtained for typical mustard slurry. The parameters that could possibly affect the shape of the force-displacement curve are height of the cell, annulus width, plunger shape, plunger speed, and clearance at the end of the test between the lower face of the plunger and the inside bottom of the cell. The shape of the force-displacement curve was insensitive to cell height, plunger speed, and bottom clearance. So, these three parameters were chosen as 85 mm, 100 mm/min, and 5 mm, respectively. Extensive preliminary experiments were conducted to determine the effect of annulus width and plunger shape on the shape of the force-displacement curve. The results (Table III) for different mustard slurries were obtained by soaking whole seeds, cracked seeds, or 1:1 mixture of the two in 22 °C water for one hour. The cell with a 16.0-mm inner diameter and a cylindrical plunger with a 12.2-mm outer diameter (1.9-mm annulus), produced a force-displacement curve closest to the ideal back extrusion curve, i.e., having a long flat plateau with small variation, and therefore was selected for use in the main experiment. The dimensions of the back extrusion cell are shown on Figure 3.

In the main experiment, mustard slurry was made by soaking cracked mustard in 22 °C tap water for 5 minutes. The slurry then was placed in the test cell. The filled cell was placed in the Instron universal machine, with the plunger travelling at a speed of 100 mm/min. The force-displacement curves were recorded on strip chart and used to obtain the first peak and average extrusion forces.

TABLE III

BACK EXTRUSION CURVE CHARACTERISTICS

Cylinder	Plunger		Annulus	Seed	Constant Force Extrusion Region		
ID. mm	Shape	OD. mm	mm		Existed	Length	Variation from Mean
14.62	cyl	9.14	2.74	mixed	no		
14.62	cyl	11.18	1.72	mixed	yes	long	small
14.62	cyl	12.20	1.21	mixed	yes	long	small
14.62	sph	12.70	0.96	mixed	yes	long	large
16.00	cyl	11.18	2.41	cracked	no		
16.00	cyl	12.20	1.90	whole	yes	long	small
16.00	cyl	12.20	1.90	mixed	yes	long	small
16.00	cyl	12.20	1.90	cracked	yes	long	small
16.00	sph	12.70	1.56	whole	yes	long	small
16.00	sph	12.70	1.56	mixed	yes	long	small
16.00	sph	12.70	1.56	cracked	yes	short	small
IDEAL					yes	long	short

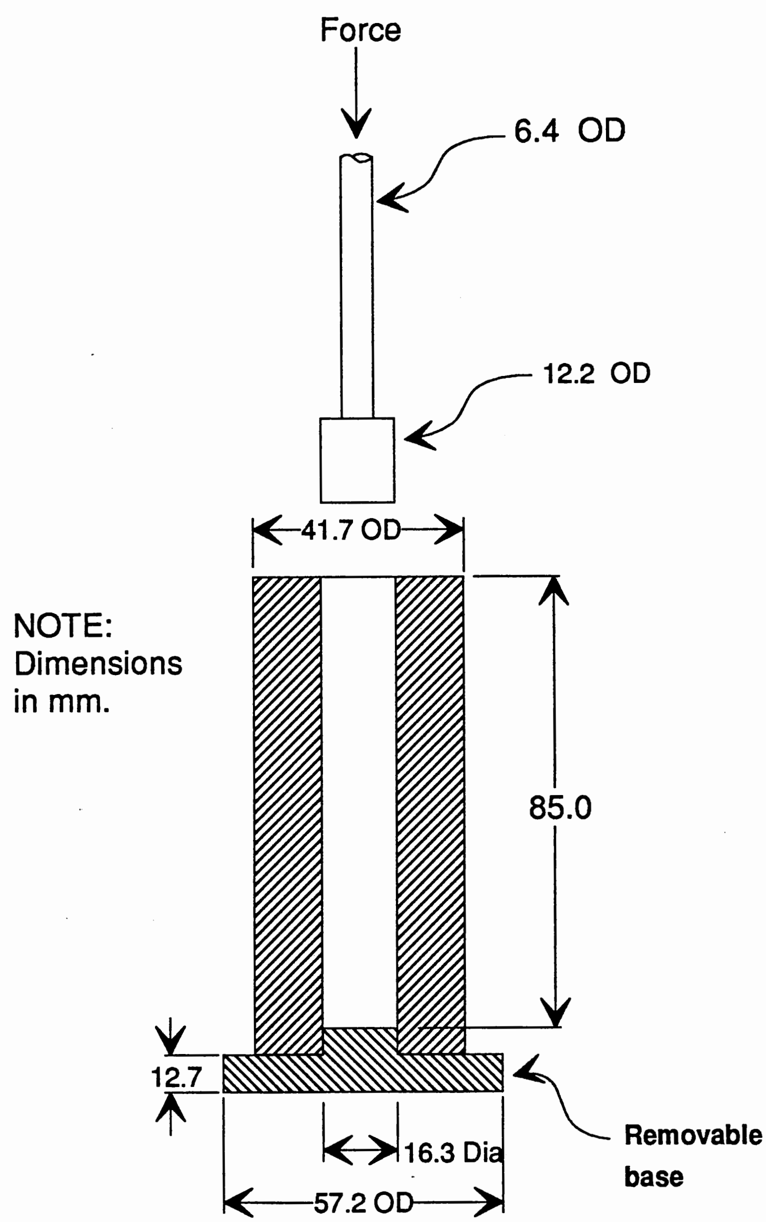

Figure 3. Back Extrusion Test Cell

Particle Size Distribution

Particle size distribution was determined by sieve analysis using 20.3-cm diameter U.S.Standard Sieve Series #7 through # 50. Preliminary tests showed that about 90% seed, by weight, was located in the size range corresponding to the #8 through #16 sieves. In this range, the intervals between successive standard sieves are relatively large. To obtain more data points for these particle sizes, three non-standard sieves were added, i.e., #11, 13, and 15 with openings of 1.854, 1.524, and 1.295 mm respectively. The 18 sieves were arranged into three groups, since the Ro-Tap shaker could handle only six sieves each time. Following the ASTM standard procedure (ASTM, 1989), a 100-g sample was shaken for two minutes. After shaking, the sieves were emptied, brushed clean, and the sample from each sieve was weighed.

The arithmetic mean for the opening sizes of two immediately successive sieves was assigned as the nominal size of the particles that passed through the larger opening sieve, but retained on the smaller opening sieve. The weight data from sieving were converted to frequency by dividing the weight on each sieve by the total weight from all sieves for that replication. Thus, all analyses were based on frequency. The results were presented in five ways; frequency vs. size distribution, cumulative distribution, arithmetic mean size, median, and fine fraction. Cumulative distribution is the distribution of the sums for the whole portion of particles that are less than the stated sizes. The data were equal to the portion that passed through the corresponding sieves, and so it was termed "total passed". Arithmetic mean size, median, and fine fraction are parameters to characterize the size distribution. The arithmetic mean size was calculated from

$$d_m = \frac{\sum_i W_i d_i}{\sum_i W_i} = \sum_i f_i d_i$$

Where W_i and f_i are the weight and frequency of the particles, respectively, with a nominal diameter of d_i.

The median ($d_{0.5}$) can be considered as a kind of opening size through which 50% of the particles could pass. This parameter was obtained by interpolating between two values of the "total passed" data that gave a range containing the value 50%. The fine fraction is the total portion passing through sieve #12 and is an indicator of the proportion of small-size particles in a sample.

An analysis of variance was conducted of the roller mill data to investigate the effects of seed temperature and roll gap on the dependent parameters. Tukey's Studentized Range (HSD) Multiple Comparison test (SAS, 1988) was employed to show differences in each dependent parameter mean between all the 11 different treatments and whole seed. In addition, the relationship among the dependent variables was investigated using Pearson's correlation coefficients.

CHAPTER IV

RESULTS AND DISCUSSION

The data from whole mustard seeds were also included with the 11 different cracking treatments for comparison purposes. Table IV shows the mean values of bulk density, bulk compressibility, and back extrusion force for each set of cracking conditions and whole seeds, and also the results of statistical analysis. Table VII is similar but shows the effect on particle size parameters. More data are shown in the Appendix.

Bulk Density

For roller milling, seed bulk density was less at lower seed cracking temperature and narrower roll gap, and for hammer milling, bulk density was less at the lower feed rate (Table IV and Figure 4). The largest reduction in bulk density caused by milling was 34%; that is, the bulk density of 720 kg/m^3 for whole seeds changed to 473 kg/m^3 for particles cracked at 5 °C by the roller mill set at a roll gap of 0.3 mm. The smallest reduction in bulk density, 9%, occurred for seeds cracked through the hammer mill at a feed rate of 29 kg/min.

In roller mill cracking, the effects of seed temperature and roll gap interacted, with an observed significant level of 0.0001 for "no interaction" from the analysis of variance (Table V). There were obviously seed temperature effects at gaps of 0.3

TABLE IV

BULK DENSITY, BULK COMPRESSIBILITY, AND BACK EXTRUSION FORCE
AS AFFECTED BY CRACKING TREATMENT

Treatment: Mill	Treatment: Temp. (°C)	Bulk Density (kg/m3)	Bulk Compression Force (kg)	Back Extrusion Peak Force (kg)
Roller Mill Gap=				
0.3 mm	5	473.48 (2.7) i	30.80 (6.0) i	8.84 (10.9) ef
	20	504.23 (2.8) h	38.00 (7.8) i	8.23 (9.4) f
	35	531.14 (2.0) fg	51.92 (8.8) h	8.19 (10.4) f
0.5 mm	5	514.48 (3.2) gh	54.60 (7.1) h	10.73 (11.9) def
	20	538.19 (3.1) ef	74.22 (8.4) g	11.48 (13.0) de
	35	616.35 (1.5) cd	100.03 (5.5) ef	10.94 (8.7) def
0.7 mm	5	614.43 (0.8) cd	111.80 (6.6) e	12.00 (12.6) cde
	20	604.82 (3.2) d	134.07 (5.6) d	13.56 (12.5) cd
	35	627.89 (1.4) c	185.57 (5.8) c	13.65 (14.0) cd
Hammer Mill Feed Rate=				
17 kg/min	20	553.56 (1.7) e	98.26 (3.4) f	14.75 (9.6) c
29 kg/min	20	654.80 (1.1) b	217.39 (8.9) b	27.50 (16.0) b
Whole Seed		720.15 (0.5) a	488.33 (2.4) a	51.47 (8.0) a

1. The data are the means of 10 replications, with the coefficients of variation in parentheses.
2. The data in the same column with at least one letter in common are not significantly different, by Tukey's Studentized Range test at 0.05 level.

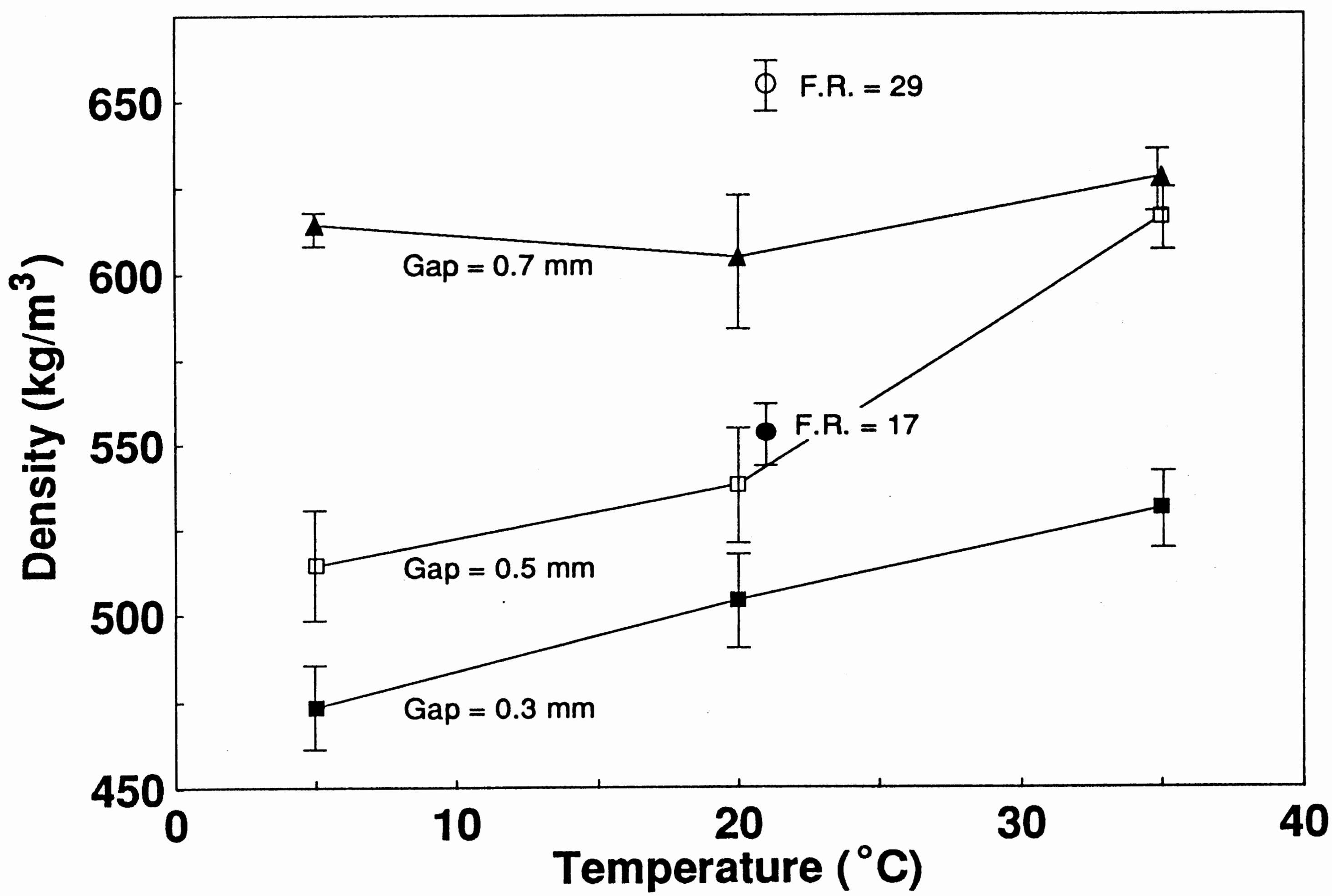

Figure 4. Bulk Density as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate. The Bar at Each Data Point Represents the Standard Deviation from the Mean.

TABLE V

ANALYSIS OF VARIANCE FOR ROLLER MILLING

Independent Parameter	Source	F Value	Pr > F
Bulk Density	Temp.	151.94	0.0001
	Gap	539.87	0.0001
	Temp.*Gap	31.72	0.0001
Bulk Compressibility	Temp.	440.10	0.0001
	Gap	2157.35	0.0001
	Temp.*Gap	48.99	0.0001
Back Extrusion Force	Temp.	1.46	0.2391
	Gap	93.06	0.0001
	Temp.*Gap	2.53	0.0465
Fine Fraction	Temp.	386.09	0.0001
	Gap	430.45	0.0001
	Temp.*Gap	84.01	0.0001

and 0.5 mm, but not at a 0.7-mm gap. When seeds were cracked at 5 °C, a larger difference in bulk density existed between gaps of 0.5 and 0.7 mm, while cracking at 35 °C produced a larger difference between 0.3 and 0.5-mm gap, and only a little difference between gaps of 0.5 and 0.7 mm.

Bulk Compressibility

The bulk compression force decreased drastically as mustard seeds were cracked by any of the 11 treatments (Figure 5 and Table IV). The bulk compression force was higher at higher seed cracking temperature, wider gap roller mill, and higher feed rate hammer mill. Bulk compression force decreased 94% for seeds cracked at 5°C by a 0.3-mm gap roller mill.

For roller milling, an interaction also existed between seed cracking temperature and roll gap (Table V). Seed temperature showed a relatively large effect on bulk compressibility at a 0.7-mm roll gap, but no effect at a 0.3-mm gap. The gap effect became slightly more significant at higher seed cracking temperatures.

Back Extrusion Force

The peak and average back extrusion force were affected similarly by the milling treatments (Table VIII in Appendix). The Pearson Correlation Coefficient for peak and average value of back extrusion force was as high as 0.99 (Table VI). Peak force was selected for use, because it was more precisely determined from the force-deformation curve.

The back extrusion force was considerably reduced by any of the cracking

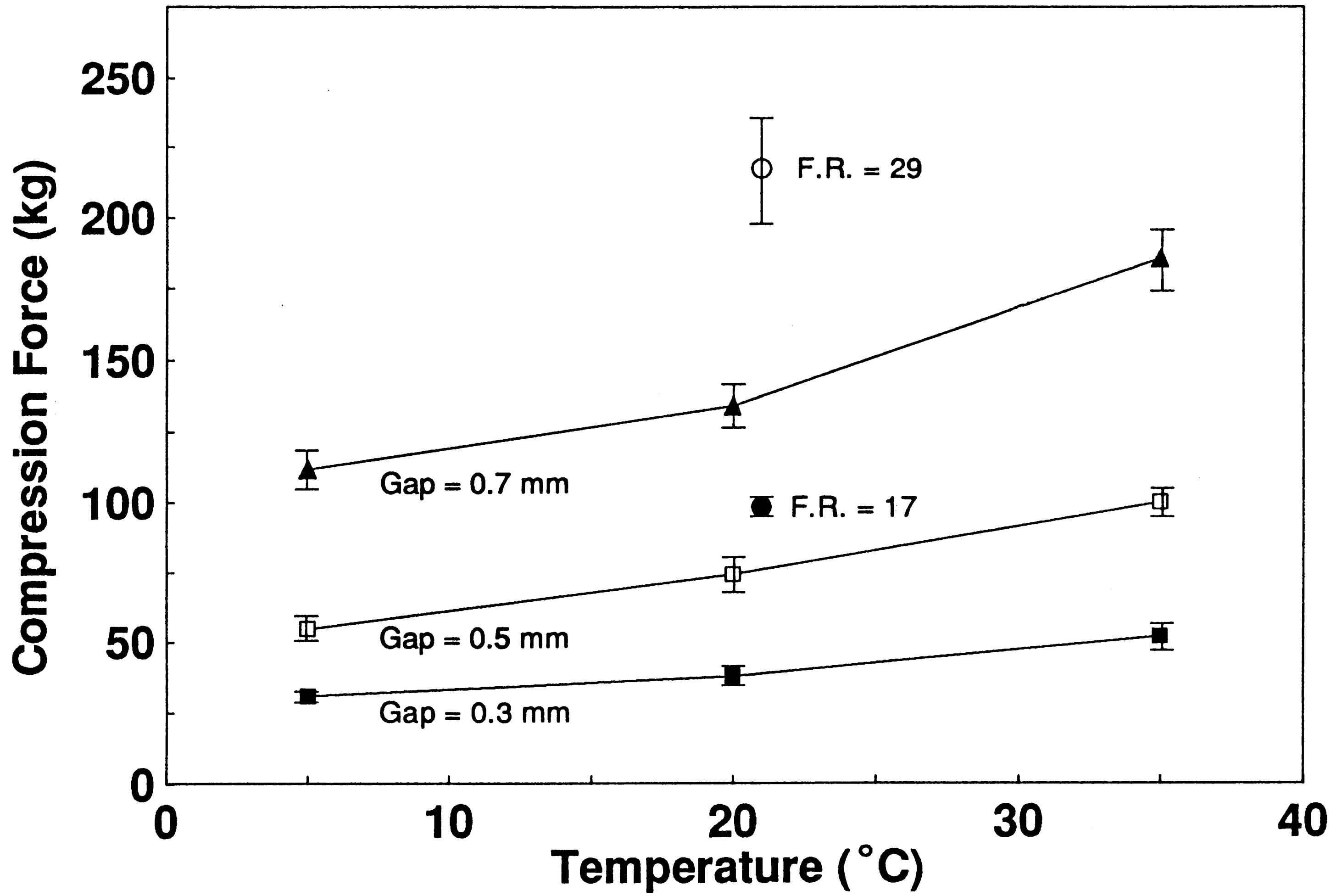

Figure 5. Bulk Compressibility as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate

TABLE VI

CORRELATION COEFFICIENTS BETWEEN THE INDEPENDENT VARIABLES

	Bulk Density	Bulk Compress	Back Extrusion Peak Force	Back Extrusion Average Force	Arithmetic Mean Particle Size	Median Particle Size	Fine Fraction
Bulk density	1.000 * 0.0	0.876 0.0002	0.785 0.0025	0.781 0.0027	0.644 0.0239	0.402 0.1951	-0.690 0.0131
Bulk compression	......	1.000 0.0	0.969 0.0001	0.973 0.0001	0.442 0.1506	0.259 0.4158	-0.497 0.1003
Back extrusion peak force	....		1.000 0.0	0.998 0.0001	0.266 0.4041	0.139 0.6662	-0.324 0.3037
Back extrusion average force	....			1.000 0.0	0.286 0.3681	0.144 0.6551	-0.342 0.2759
Arithmetic mean particle size	....				1.000 0.0	0.865 0.0003	-0.996 0.0001
Median particle size	....					1.000 0.0	-0.863 0.0003
Fine fraction	....						1.000 0.0

* Values for Prob>|R| /H0: Rho=0.

treatments (Figure 6 and Table IV). For roller milling, a wider gap resulted in a slightly higher back extrusion force. Changing seed cracking temperature made no difference in back extrusion force. An analysis of variance test for 9 roller milling treatments (Table V) showed that gap had a significant effect, but not temperature (0.239 Pr>F value). For hammer milling, the feed rate of 29 kg/min produced a back extrusion force much larger than the 17-kg/min feed rate, and also larger than any roller mill treatments. Back extrusion force was reduced the most by the 0.3-mm gap roller mill and the least by the high feed rate hammer mill.

Particle Size Distribution

Lower seed cracking temperature and narrower gap roller milling, or lower feed rate hammer milling reduced both the arithmetic mean and median, and increased the fine fraction of the cracked seed (Table VII and Figures 7 - 9). Of all 11 treatments, the most effective one in size reduction was 17-kg/min feed rate hammer milling, which increased the fine fraction more than 13 times that for whole seed, and also reduced the arithmetic mean and median the most. The smallest size reduction occurred with 0.7-mm gap roller milling, which produced almost no change from whole seed.

For roller milling, seed temperature and gap had an interaction effect on all of the three size parameters. The gap affected the size reduction greatly at 5 °C, but not at 35 °C. The temperature effect was significant at a gap of 0.3 or 0.5 mm, but not at a 0.7-mm gap.

For a more detailed analysis of particle size, the entire frequency distributions

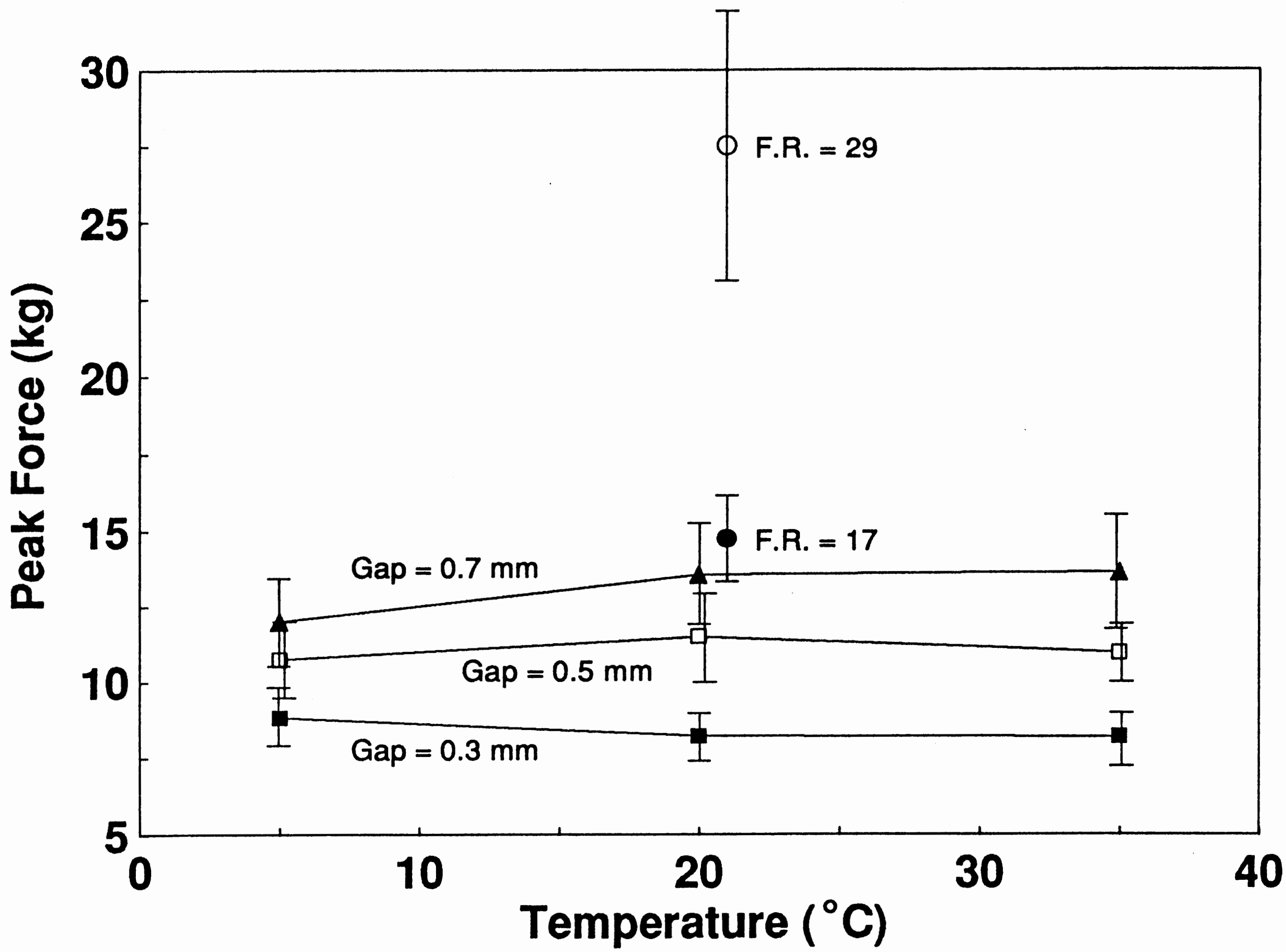

Figure 6. Back Extrusion Force as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate

TABLE VII

PARTICLE SIZE DISTRIBUTION AS AFFECTED BY CRACKING TREATMENT

Treatment: Mill	Treatment: Temp. (°C)	Arithmetic Mean Particle Size (mm)	Median Particle Size (mm)	Fine Fraction (%)
Roller Mill Gap (mm):				
0.3	5	1.56 (1.7)	1.75	47.33 (3.6)b
	20	1.78 (3.2)	1.92	30.25 (11.0)d
	35	1.89 (2.4)	1.96	20.76 (13.6)f
0.5	5	1.63 (1.7)	1.86	41.50 (5.1)c
	20	1.83 (4.5)	1.93	25.64 (16.0)e
	35	2.04 (1.8)	1.99	5.64 (5.1)i
0.7	5	1.98 (1.5)	1.97	10.39 (13.5)gh
	20	1.98 (2.3)	1.98	12.20 (15.0)g
	35	2.01 (1.5)	1.98	7.59 (7.0)hi
Hammer Mill Feed Rate (kg/min):				
17	20	1.48 (1.7)	1.48	55.98 (1.4)a
29	20	1.74 (1.8)	1.90	29.97 (6.5)de
Whole Seed		2.03 (1.5)	1.98	3.88 (3.4)i

1. The data are the means of 6 replications, with the coefficients of variation in parentheses.
2. The data in the same column with at least one letter in common are not significantly different, by Tukey's Studentized Range test at 0.05 level.

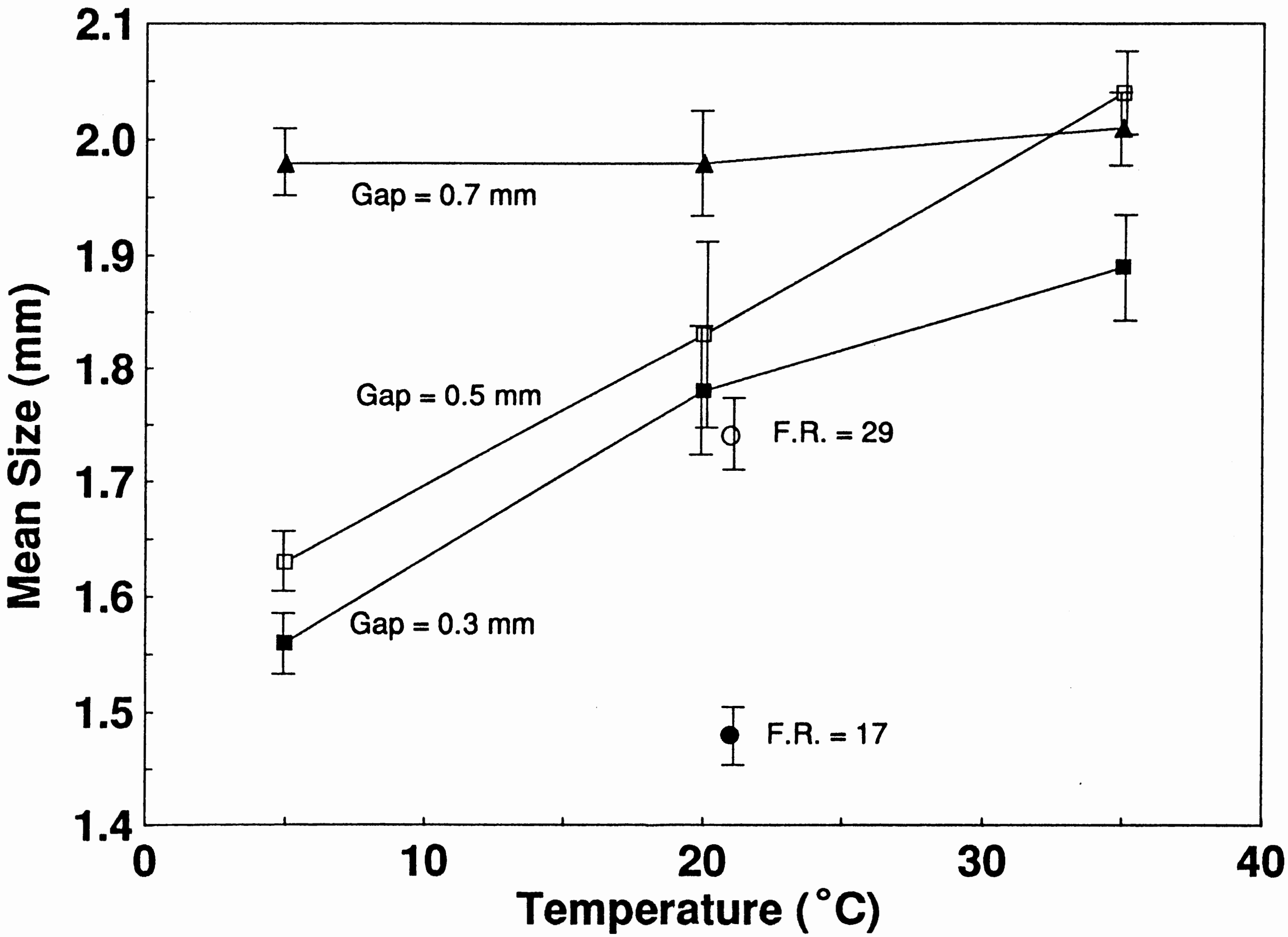

Figure 7. Arithmetic Mean Particle Size as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate

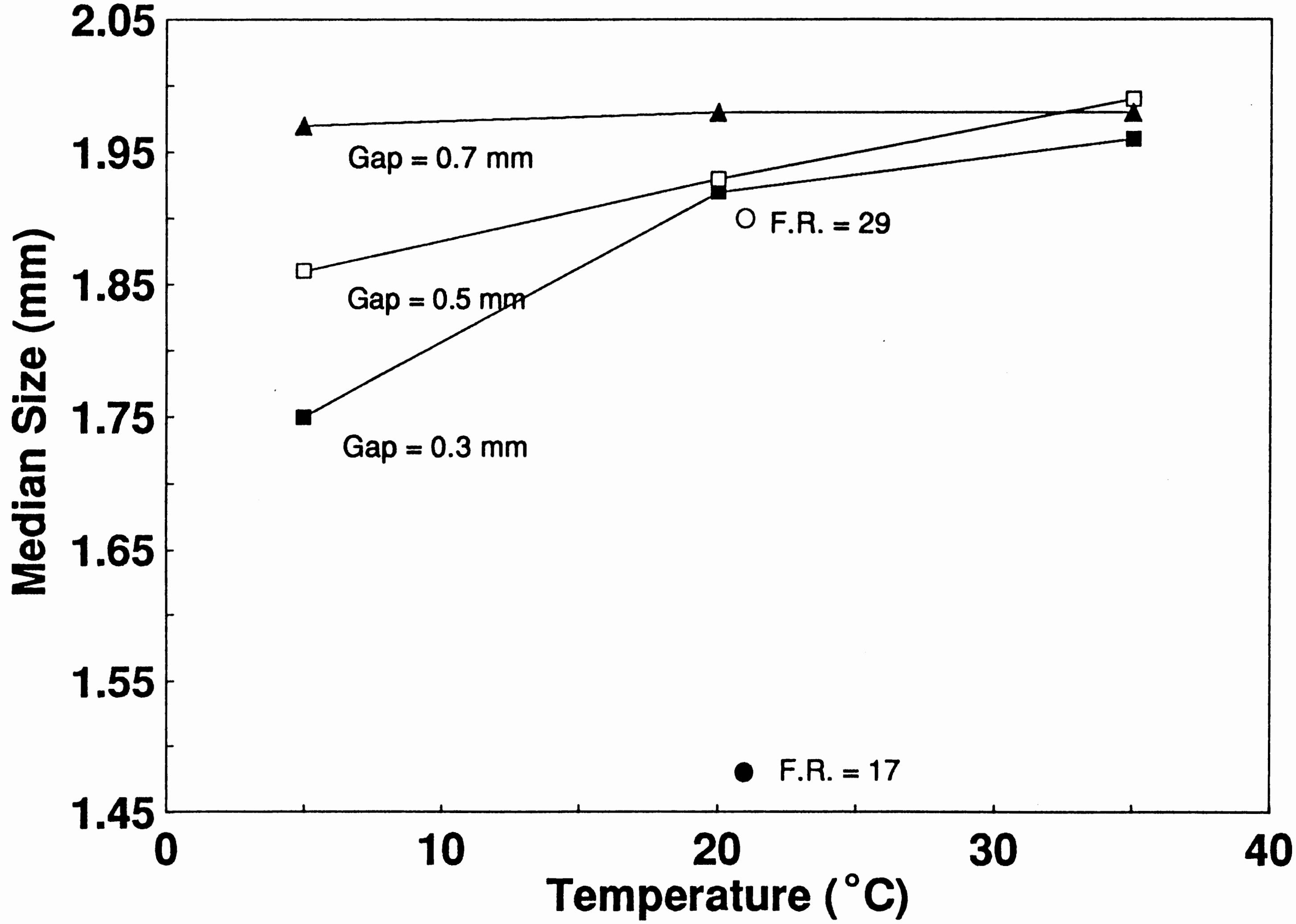

Figure 8. Median Particle Size as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate

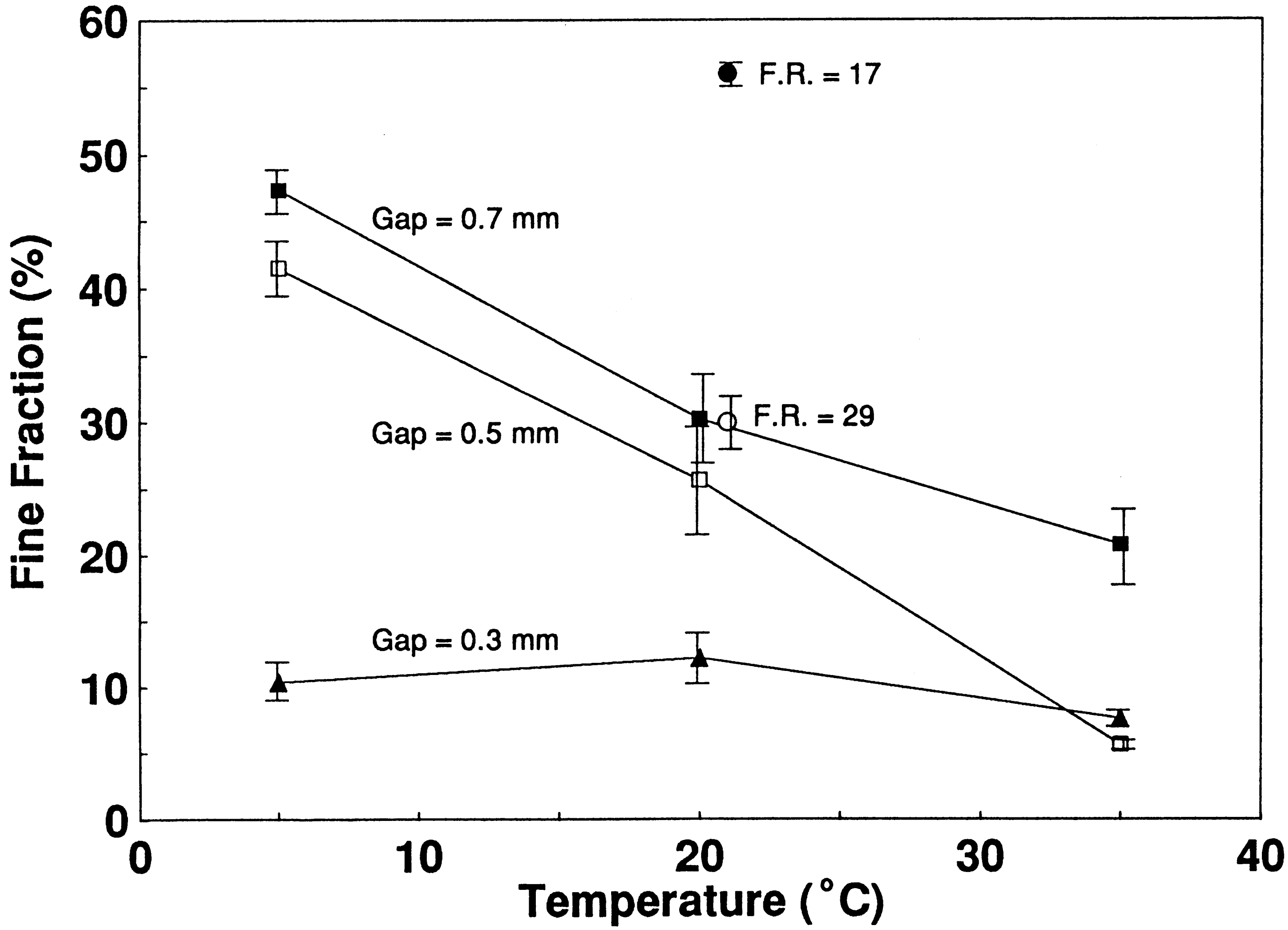

Figure 9. Fine Fraction of Particles as Affected by Roller Mill Gap, Seed Cracking Temperature, and Hammer Mill Feed Rate

are presented in Figures 10 through 12 for some treatments and also in Figure 13 through 15 for the cumulative distributions. Whole seed is narrowly distributed in the size range from about 1.5 mm to 3.0 mm. After cracking, the distribution shifts towards smaller particles. The reduction in large particles (> 1.6 mm) was matched by an increase in small particles (< 1.6 mm) with an almost constant weight frequency at a size of 1.6 mm. Since the nominal size of 1.6 mm corresponds with the sieve #13, the sum of particles equal to or smaller than 1.6 mm can be considered as a dividing line for the parameter, "fine fraction".

After passing through a 0.3-mm gap roller mill, the particle distribution obviously differed from whole seed, and a much greater change was made by cracking at a lower seed temperature (Figure 10 and 13). Any sample cracked by a 0.7-mm gap roller mill showed little change in size distribution from whole seed, irrespective of seed temperature when cracked (Figure 11 and 14). Furthermore, they had slightly more large particles (size ≥ 2.6 mm) than whole seed. This result suggested that some seeds had been cracked or deformed to a shape that actually increased their size, at least in some dimensions. Apparently, some milling treatments do not necessarily reduce the size of all particles.

Hammer milling caused a great change in size distribution from whole seed, and more fine particles were produced at the lower feed rate than at the higher feed rate (Figure 12 and 15). The distribution of hammer milled particles was different from roller milled seed in the large particle range as indicated by a smaller mode. The 20 °C, 0.3-mm gap roller milled sample was distributed very similarly to the 29-kg/min feed rate hammer milled sample, except for the mode in the large particle

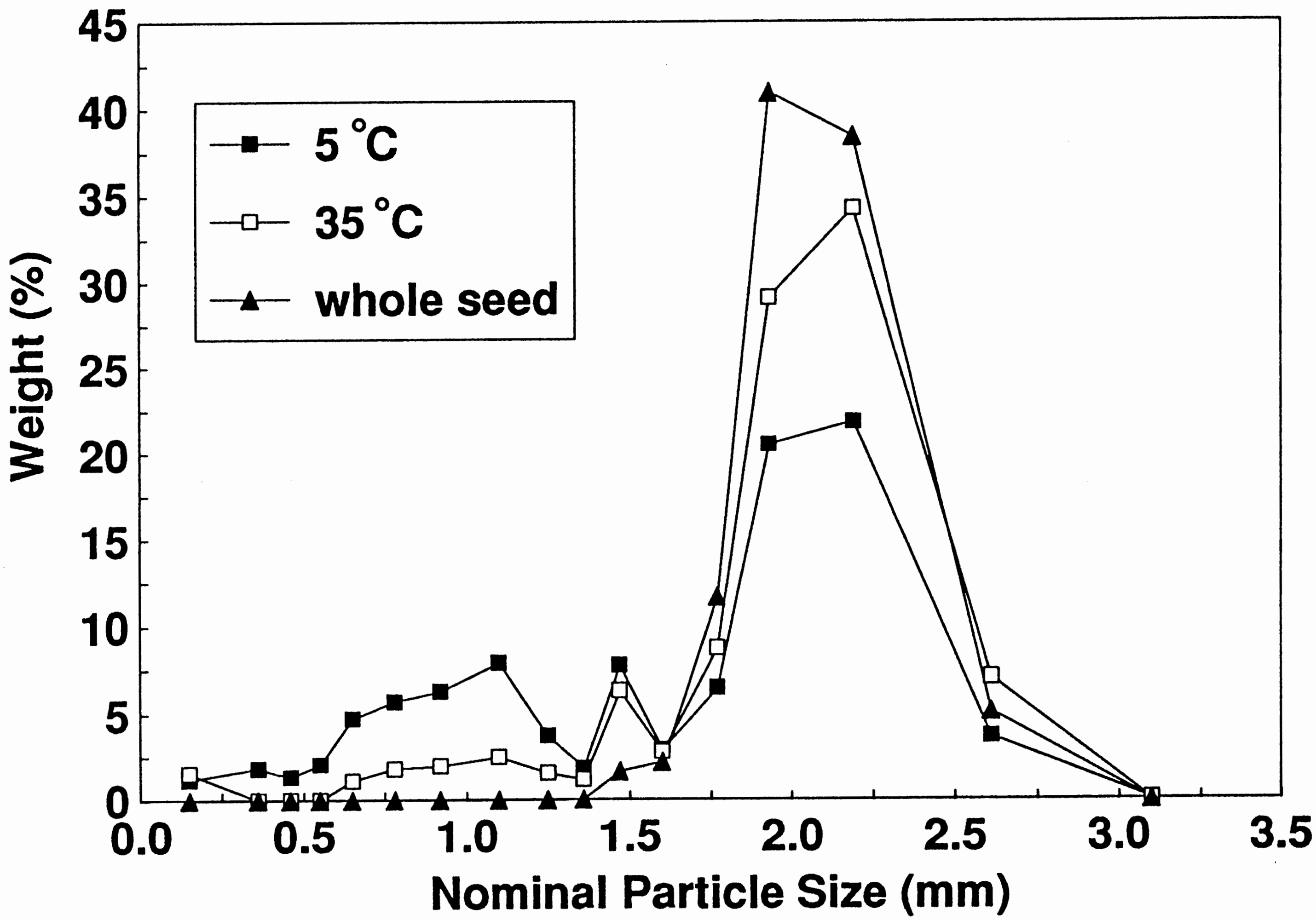

Figure 10. Particle Size Frequency Distribution Before and After Roller Milling at 0.3 mm Gap

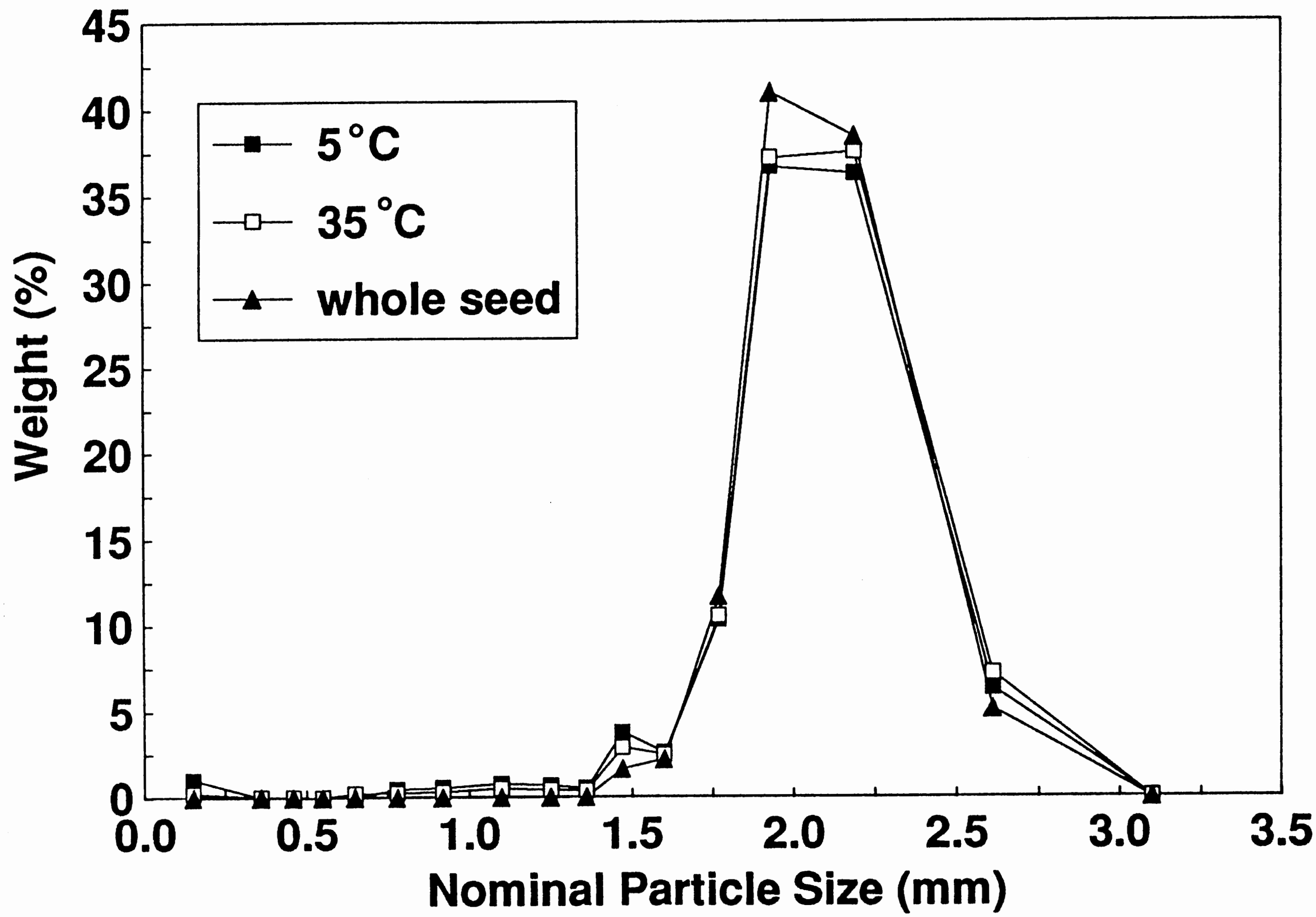

Figure 11. Particle Size Frequency Distribution Before and After Roller Milling at 0.7 mm Gap

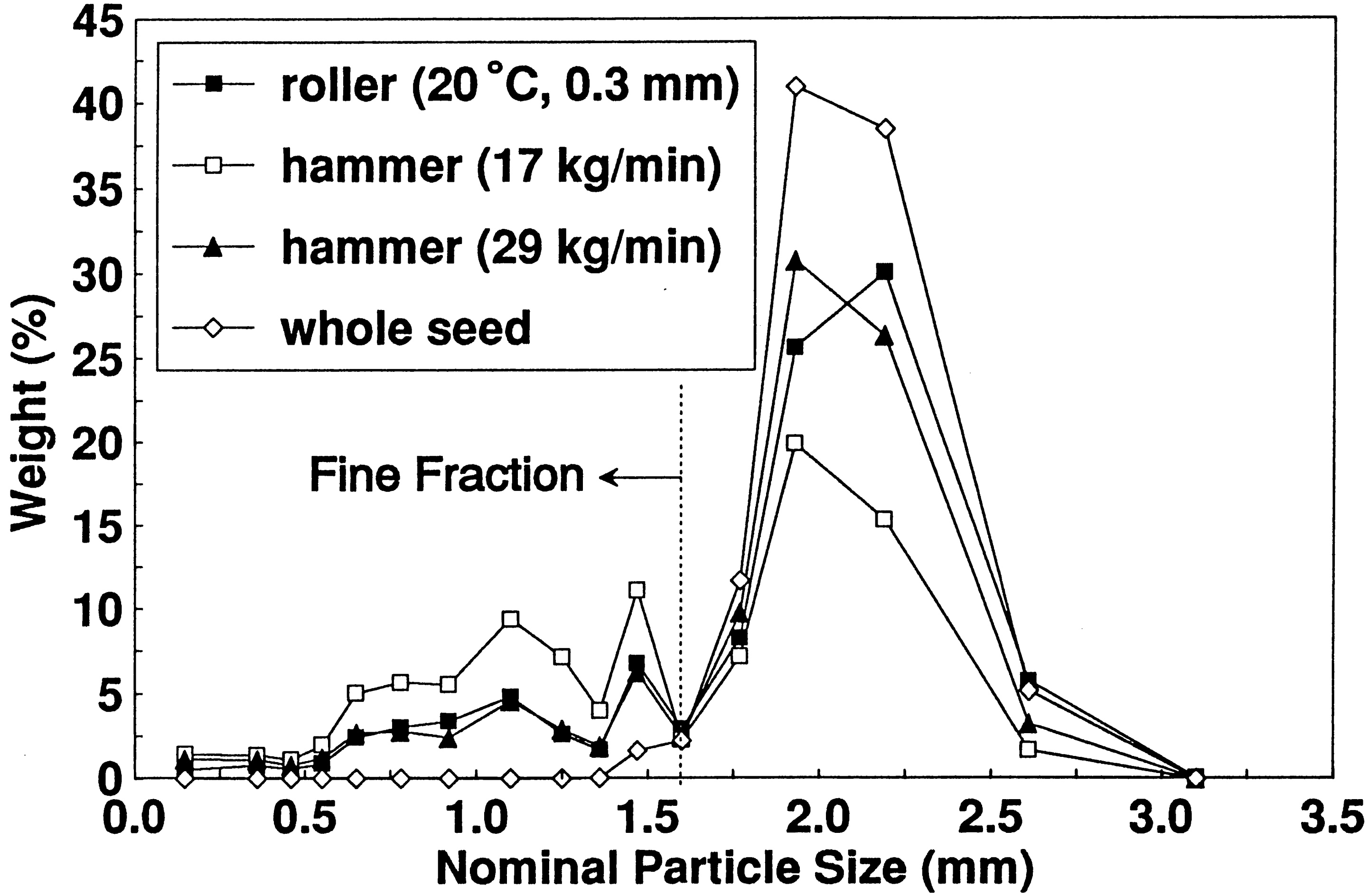

Figure 12. Particle Size Frequency Distribution Before and After Hammer Milling or Roller Milling at 0.3 mm Gap, 20 °C. Fine Fraction Is Defined as All Particles Passing Through Sieve #12 (1.68 mm).

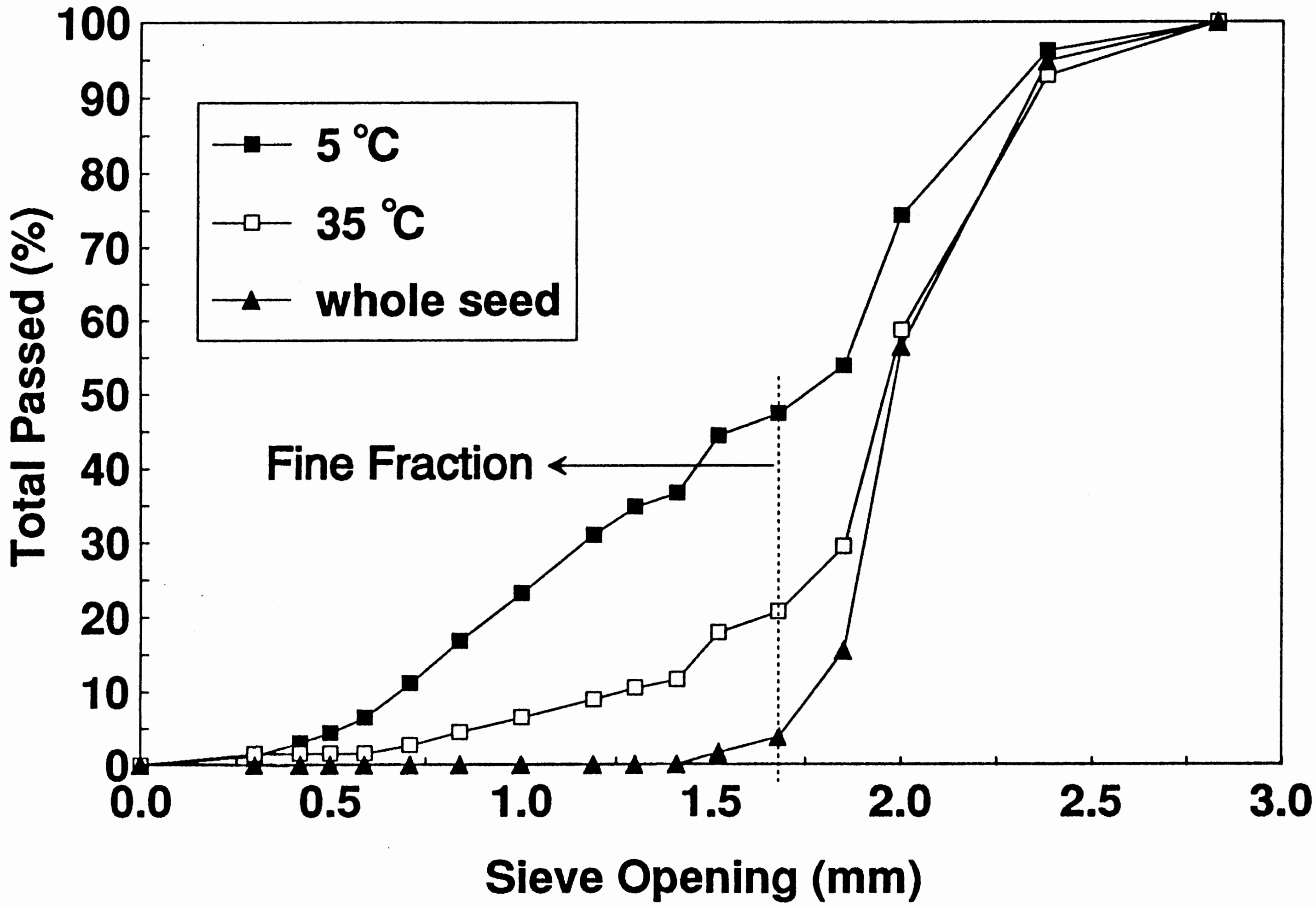

Figure 13. Cumulative Particle Size Distribution Before and After Roller Milling at 0.3 mm Gap

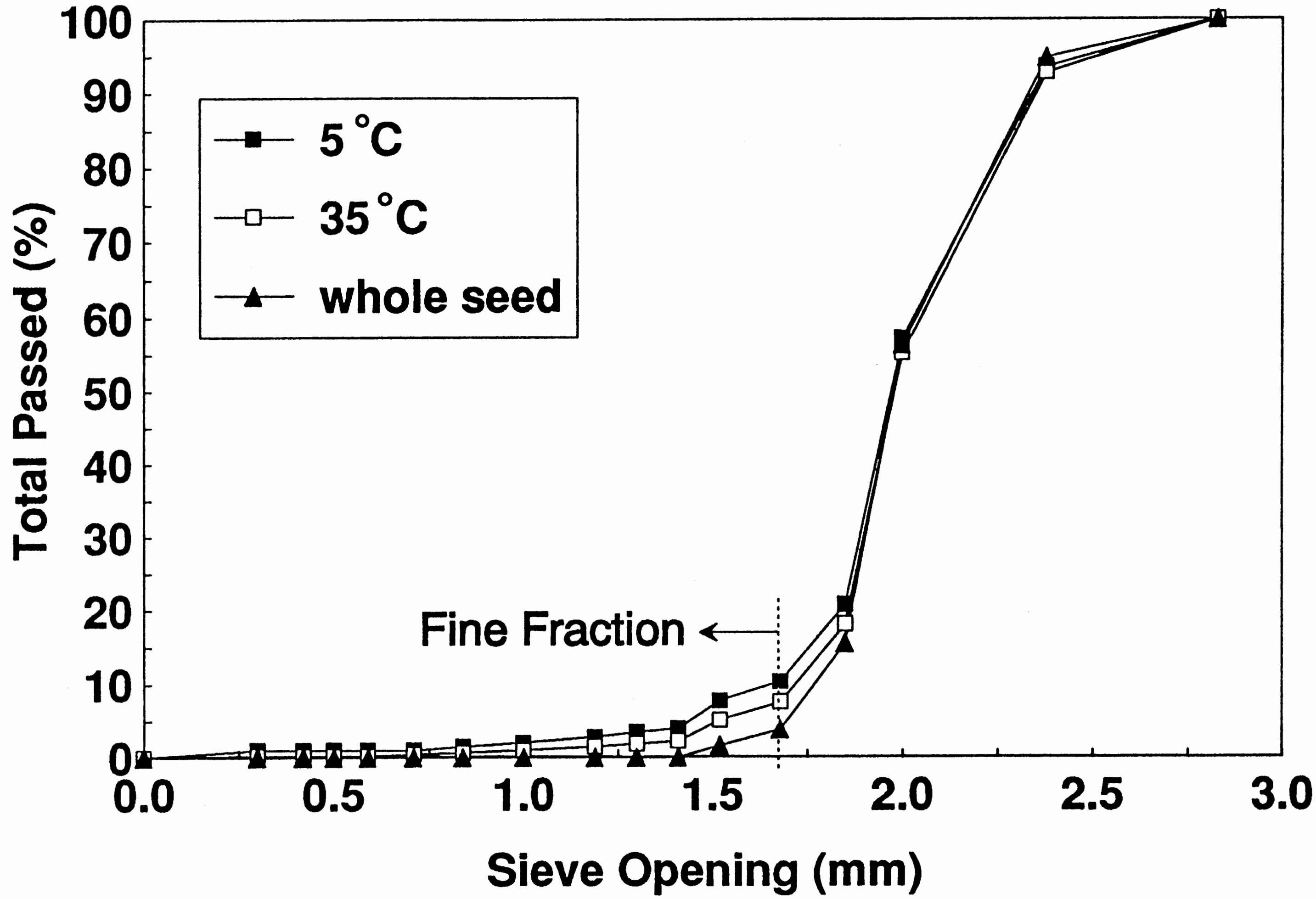

Figure 14. Cumulative Particle Size Distribution Before and After Roller Milling at 0.7 mm Gap

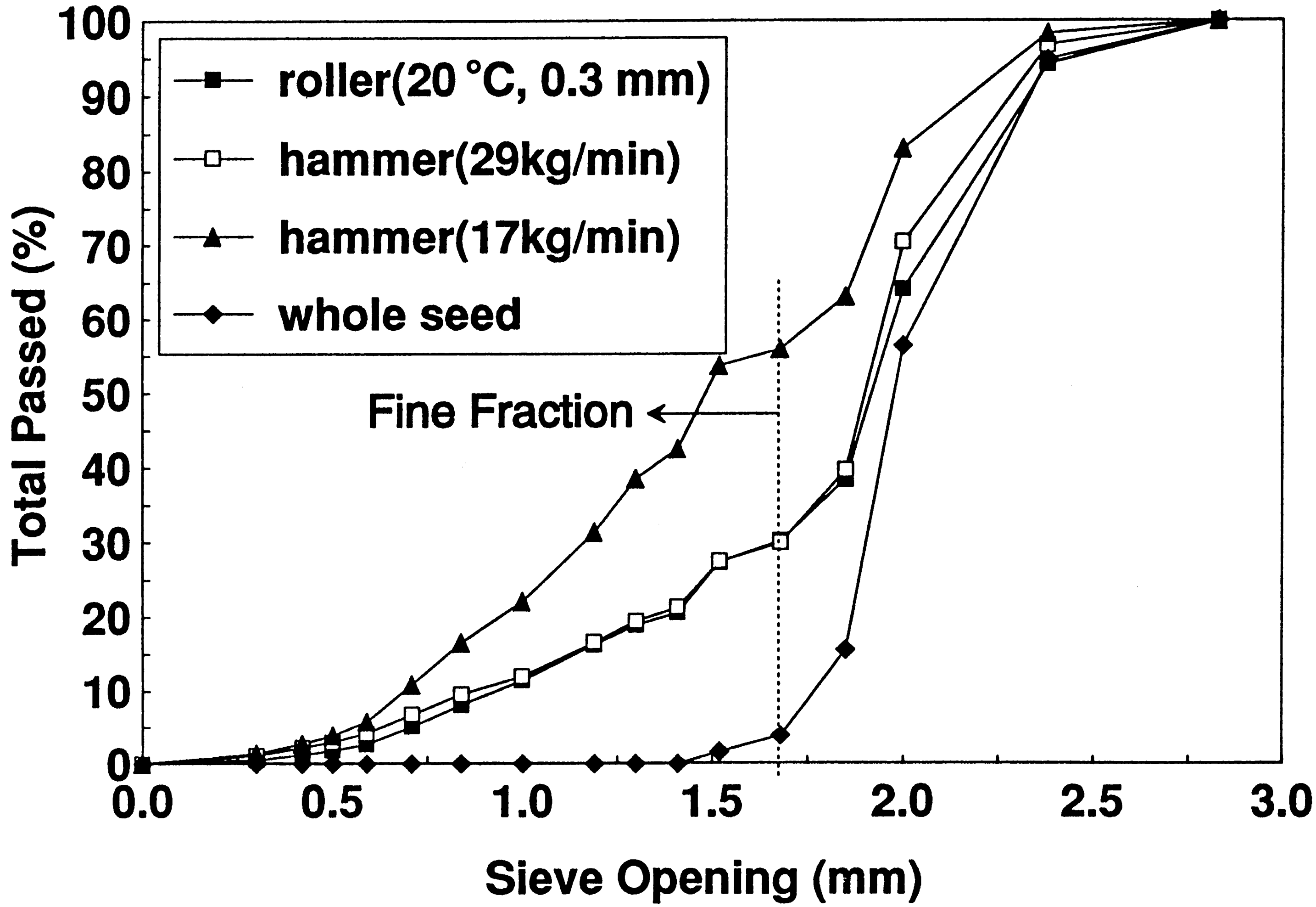

Figure 15. Cumulative Particle Size Distribution Before and After Hammer Milling and Roller Milling at 0.3 mm Gap, 20 °C

range.

Discussion

Difference Between Mills

According to the size distribution analysis, either hammer milled sample is finer than any of the 20 °C roller milled samples, while hammer milled seeds had the bulk properties, i.e., bulk density, bulk compression force, and back extrusion force closer to whole seeds than roller seeds. A higher density-to-particle-size ratio for hammer milled particles compared with roller milled ones was also reported by Appel (1986). A possible explanation is the different shapes of particles from the two mills. Hammer milled seeds are mostly short and straight shaped, while roller milled seeds contain many long, curved shaped particles, which is consistent with the Appel's report of a higher surface area/gram ratio produced by roller milling. When filled into a bulk property test cell, hammer milled particles pack more tightly than roller milled particles, even though they are finer. The hammer milled particles thus produce a relatively large compression force, back extrusion force, and bulk density.

Relationship Among Dependent Variables

The relationship among the dependent parameters was determined by computing Pearson's correlation coefficient between any pair of the dependent variables (Table VI). The correlation coefficients (R) between back extrusion peak force and back extrusion average force, and between arithmetic mean particle size and fine fraction are above 0.99. This high correlation indicates that of each pair, only one parameter is necessary to describe cracked mustard. Among the three bulk parameters, bulk compression was the most highly correlated with both bulk density (R=0.88) and back extrusion force (R=0.97), while, between bulk density and back extrusion force, the correlation was relatively low (0.78). Back extrusion force had the lowest correlation with any size parameter, i.e., arithmetic mean, median, or fine fraction, with a Prob>|R| value as large as 0.67. Bulk density had the highest correlation with these size parameters. This result suggests that back extrusion force is independent of the particle size distribution of the cracked mustard. Bulk density is most related to particle size, especially arithmetic mean and fine fraction.

Sensitivity of Dependent Variables

The difference in each dependent parameter between any two cracking treatments was tested by the Tukey's Studentized Range Multiple Comparison analysis. Any two numbers in the same column of Table IV or Table VII with at least one letter in common are not significantly different at the 0.05 level. More different letters in a column and fewer different letters behind each number in the column shows that more differences were detected and that property parameter is more sensitive to treatment effects. By this criterion, bulk compression is the most sensitive, fine fraction is the second, and back extrusion force the least sensitive in detecting the difference in milling treatment.

Of the three single size parameters, fine fraction, as a specially defined partial sum, is the most straight-forward to determine and is more sensitive than median particle size as shown by cumulative distribution curves (Figure 13 through 15). The size corresponding with 50% of total passed is the median of the sample, and the total passed value corresponding with a sieve opening of 1.68 mm (sieve #12) is the fine fraction. Median particle sizes of different treatments changed proportionally less than the fine fraction. For example, in Figure 13, the median for the three curves varied in a range about 1/6 of the whole range for sieve opening size, but the fine fraction varied in a range about half of the range for the total passed values. This sensitivity results from properly selecting 1.6-mm nominal particle size as the cut-off point for fine particles, that is, defining fine fraction as the sum of particles passed through sieve #12 (opening 1.68 mm).

The nominal particle size of 1.6 mm is a size dividing the distribution curves into two regions (Figure 10 through 12). In Figure 12, in the smaller than 1.6 mm particle size range, the distribution curve of 17-kg/min feed rate hammer milled sample is above the curve for the 29-kg/min feed rate sample, while for sizes larger than 1.6 mm, the low feed rate distribution is below the high feed rate curve. Thus, using the sum of particles equal to or smaller than 1.6 mm, i.e., fine fraction, or the sum of particles larger than 1.6 mm, will yield the greatest difference between treatments. The largest difference in the total passed value is located at the sieve opening of 1.68 mm, i.e., sieve #12 (Figures 13 through 15).

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Mustard manufacturing starts with cracking whole mustard seed in a mill. Physical property control of this initial milling stage is important to guarantee the final textural quality of product, which influences the consumer's acceptance of the product.

An investigation of the cracking operation was conducted to determine the effects of mill type (hammer vs. roller), gap between rolls of the roller mill, seed temperature at cracking, and hammer mill feed rate on the physical properties of the cracked mustard. Samples from 11 cracking treatments, together with the whole seed, were tested for bulk density, bulk compressibility, back extrusion force, and size distribution.

Lower seed cracking temperature and narrower gap for roller milling, and lower feed rate for hammer milling produced finer particles, with a lower bulk density, bulk compression force, and back extrusion force. The lowest bulk density, bulk compression force, and back extrusion force were found for seed cracked at 5 °C with 0.3-mm gap roller mill, while the most fine particles resulted from the 17-kg/min feed rate hammer mill. Back extrusion force was similar for all treatments.

The correlation among the dependent parameters showed that, of the three bulk parameters, bulk density is the most highly related to particle size distribution (R=0.7), while back extrusion has the lowest correlation (R=0.3). Bulk compression force is the most sensitive, fine fraction is the second, and back extrusion force is the least sensitive in detecting treatment differences.

Conclusions

The following conclusions may be drawn from this study:

1. All of the 11 cracking treatments tested significantly reduced back extrusion force and bulk compression force compared with whole seed.

2. The effects of roll gap and seed temperature on roller milling were best shown by particle size distribution, while their effect was nearly undetectable by back extrusion.

3. There was an interaction effect between roll gap and seed cracking temperature on all the physical properties tested, except back extrusion force.

4. Changing the hammer mill feed rate from 29 to 17 kg/min reduced particle size considerably, as shown by all of the measured physical properties.

5. The bulk properties, bulk density, bulk compressibility, and back extrusion force were closer to the whole seed properties for hammer milled seed than for roller milled seed at the same cracking temperature. Hammer milling did, however, produce more fine particles.

6. Of the 11 treatments, cracking 5 °C seed through a 0.3-mm gap roller mill produced particles of lowest bulk density, bulk compression force, and back extrusion force, while 17-kg/min hammer milling produced the most fine particles. Size

distribution of particles produced by cracking 35 °C seed through 0.7-mm gap roller mill was similar to the distribution for whole seed.

7. Back extrusion force was not related to any of the particle size parameters and was the least sensitive in detecting differences among cracking treatments. Bulk compression force was the most sensitive and the fine fraction from the particle size distribution was the second most sensitive indicator of cracking treatments.

CHAPTER VI

RECOMMENDATIONS

This study focused on how the physical properties of cracked mustard seed were affected by cracking treatments during initial cracking. The ultimate purpose of this research on condiment mustard processing is to control the textural quality of the final product. Thus, the next step should study how these physical properties from the initial cracking affect the quality of final stone mill grinding. Bulk compressibility and particle size distribution are the most sensitive to the initial cracking treatments, but whether or not this sensitivity is meaningful to the ultimate purpose depends on if these properties are critical in determining final textural quality. The insensitivity of back extrusion force to the initial cracking treatments suggests that the energy consumption during the final grinding may be similar for all mustard cracking treatments, but this needs to be confirmed by tests.

One important purpose of size reduction is to increase particle surface area. Because of the large variation in shape of cracked mustard seed, this parameter can not be simply represented by particle diameter, as for spherical particles. In this study, the shape difference was indirectly determined by measuring some bulk properties, in addition to particle size distribution. The results obtained possibly involve effects from factors other than particle shape or size. A further investigation on surface area per unit volume should be conducted by a relatively direct approach such as machine vision.

Investigations on other seeds (Ituen and Adeoti, 1985; Appel, 1986) showed that seed moisture content at cracking affects the particle size distribution of cracked seed, and this effect varies with different seeds. A study on mustard cracking should be done to consider the effects of seed moisture content.

REFERENCES

Aguilar, C., S. S. H. Rizvi, J. F. Ramirez, and A. Inda. 1991a. Rheological Behavior of Processed Mustard. I. Effect of Milling Treatment. J. of Texture Studies, 22: 59-84.

Aguilar, C., S. S. H. Rizvi, J. F. Ramirez, and A. Inda. 1991b. Rheological Behavior of Processed Mustard. II. Storage Effects. J. of Texture Studies, 22: 85-103.

Alviar, M. S. B. and D. S. Reid. 1990. Determination of Rheological Behavior of Tomato Concentrates Using Back Extrusion. J. of Food Science, 55(2): 554-555.

American Society for Testing and Materials. 1990. Annual Book of ASTM Standards. C371-89: Standard Test Method for Wire-Cloth Sieve Analysis of Nonplastic Ceramic Powders. Pennsylvania: American Society for Testing and Materials.

American Society of Agricultural Engineers. 1989. ASAE Standard S352.1: Moisture Measurement - Grains and Seeds. MI: American Society of Agricultural Engineers.

Anzaldua-Morales, A. and J. G. Brennan. 1982. Relationship between the physical Properties of Dried Beans and Their Textural Characteristics After Processing. J. of Texture Studies, 13: 229-240.

Appel, W. B. 1986. Comparison of Hammermill and Roller Mill Grinding of Grain Sorghum and Corn. unpublished M.S. thesis. Kansas State University, Manhattan.

Bourne, M. C. and J. C. Moyer. 1968. The Extrusion Principle in Texture Measurement of Fresh Peas. Food Technology, 22: 1013-1017.

Cagampang, G. B., A. W. Kirleis, and J. S. Marks. 1984. Application of Small Sample Back Extrusion Test for Measuring Texture of Cooked Sorghum Grain. J. of Food Science, 49: 278-280.

Canovas, G. V. B. and M. Peleg. 1983. Flow Parameters of Selected Commercial Semi-Liquid Food Products. J. of Texture Studies, 14: 213-234.

Dallavalle, J. M. 1948. Micromeritics, 2nd ed. Theory of Fine Grinding: Surface-Area and Energy. New York: Pitman Publishing Corporation.

DeMan, J. M., P. W. Voisey, V. F. Rasper, and D. W. Stanley. 1976. Rheology and Texture in Food Quality. Interpretation of Force Curves from Instrumental Texture Measurements: Extrusion-Shear. Connecticut: the Avi Publishing Company, Inc.

Dervisoglu, M. and J. L. Kokini. 1986. Steady Shear Rheology and Fluid Mechanics of Four Semi-Solid Foods. J. of Food Science, 51(3): 541-625.

Dickie, A. M. and J. L. Kokini. 1983. An Improved Model for Food Thickness from Non-Newtonian Fluid Mechanics in the Mouth. J. of Food Science, 48: 57-60.

Gandhi, A. P. and M. C. Bourne. 1991. Short Communication: Effect of Pre-soaking on the Rate of Thermal Softening of Soybeans. Int. J. of Food Science and Technology, 26: 117-121.

Ituen, E. U. U. and J. S. Adeoti. 1985. Particle Size Characterization of Selected Grains Under Wet Grinding. J. of Food Process Engineering, 7: 287-305.

Jeffrey, D. J. and A. Acrivos. 1976. The Rheological Properties of Suspensions of Rigid Particles. American Inst. of Chemical Engr., 22(3): 417-432.

Kokini, J. L., J. B. Kadane, and E. L. Cussler. 1977. Liquid Texture Perceived in the Mouth. J. of Texture Studies, 8: 195.

Martin, S. A. 1985. Comparison of Hammermill and Roller Mill Grinding and the Effect of Grain Particle Size on Mixing and Pelleting. M.S. thesis. Kansas State University, Manhattan, Kansas.

Osorio, F. A. and J. F. Steffe. 1987. Back Extrusion of Power Law Fluids. J. of Texture Studies, 18: 43-63.

Reyes, V. G. and V. K. Jindal. 1990. A Small Sample Back Extrusion Test for Measuring Texture of Cooked-Rice. J. of Food Quality, 13: 109-118.

Supermarket Sales Manual. 1990. Miscellaneous Grocery. Progressive Grocer, July, 1990: 82-83.

SAS Institute Inc. 1988. SAS/STAT User's Guide: Statistics, Release 6.03 Edition. North Carolina: SAS Institute Inc.

Schubert, H. 1987. Food Particle Technology. Part I: Properties of Particles and Particulate Food System. J. of Food Engineering, 6: 1-32.

Steffe, J. F. and F. A. Osorio. 1987. Back Extrusion of Non-Newtonian Fluids. Food Technology, 41: 72-77.

APPENDIX

TABLES OF DATA

TABLE VIII

DATA FOR BULK PROPERTIES

temperature (C)	roller mill gap (mm) 0.3	0.5	0.7	hammer mill feed rate (kg/min) 17	29	whole seed
	BULK DENSITY (kg/m3)					
5	499.75	525.37	615.07	-	-	-
	474.12	493.34	608.67	-	-	-
	474.12	480.53	615.07	-	-	-
	448.49	518.97	615.07	-	-	-
	474.12	512.56	608.67	-	-	-
	474.12	525.37	621.48	-	-	-
	467.71	531.78	621.48	-	-	-
	467.71	512.56	608.67	-	-	-
	480.53	531.78	615.07	-	-	-
	474.12	512.56	615.07	-	-	-
Mean	473.48	514.48	614.43	-	-	-
StD	12.62	16.56	4.73	-	-	-
20	499.75	563.82	634.29	557.41	659.92	723.99
	499.75	563.82	621.48	570.22	666.33	718.87
	493.34	551.00	615.07	563.82	653.51	717.58
	512.56	538.19	608.67	557.41	653.51	-
	518.97	525.37	595.85	551.00	659.92	-
	506.15	525.37	583.04	551.00	659.92	-
	486.93	538.19	583.04	551.00	653.51	-
	531.78	512.56	576.63	538.19	653.51	-
	506.15	531.78	608.67	551.00	647.11	-
	486.93	531.78	621.48	544.60	640.70	-
Mean	504.23	538.19	604.82	553.56	654.80	720.15
StD	14.23	16.82	19.39	9.16	7.27	3.39
35	518.97	634.29	640.70	-	-	-
	525.37	627.89	634.29	-	-	-
	518.97	615.07	627.89	-	-	-
	525.37	608.67	627.89	-	-	-
	518.97	615.07	627.89	-	-	-
	538.19	615.07	634.29	-	-	-
	538.19	621.48	627.89	-	-	-
	544.60	608.67	621.48	-	-	-
	538.19	615.07	608.67	-	-	-
	544.60	602.26	627.89	-	-	-
Mean	531.14	616.35	627.89	-	-	-
StD	10.66	9.45	8.54	-	-	-

TABLE VIII (Continued)

temperature (C)	roller mill gap (mm) 0.3	0.5	0.7	hammer mill feed rate (kg/min.) 17	29	whole seed
			BULK COMPRESSION FORCE (kg)			
5	26.50	57.00	112.50	-	-	-
	30.00	60.00	114.50	-	-	-
	32.00	59.50	122.00	-	-	-
	33.00	58.00	118.00	-	-	-
	30.00	50.00	107.00	-	-	-
	30.00	54.50	110.00	-	-	-
	31.00	53.00	111.00	-	-	-
	32.00	53.50	121.00	-	-	-
	32.50	51.00	100.00	-	-	-
	31.00	49.50	102.00	-	-	-
mean	30.80	54.60	111.80	-	-	-
StD	1.86	3.86	7.43	-	-	-
20	37.75	83.22	137.73	99.80	204.30	495
	31.01	82.05	143.22	102.86	223.64	495
	38.24	81.12	129.91	99.88	227.45	475
	37.12	69.20	143.35	102.71	200.07	-
	41.76	65.98	127.72	94.41	205.02	-
	37.56	69.35	129.40	93.33	200.28	-
	41.27	72.48	133.43	95.43	222.95	-
	36.92	77.90	131.28	100.17	195.83	-
	39.27	69.55	121.56	97.83	244.32	-
	39.07	71.31	143.05	96.17	250.00	-
mean	38.00	74.22	134.07	98.26	217.39	488.33
StD	2.96	6.27	7.51	3.35	19.27	11.55
35	57.39	103.88	184.81	-	-	-
	59.73	95.24	209.72	-	-	-
	57.14	110.38	189.99	-	-	-
	48.60	107.69	181.44	-	-	-
	47.86	99.88	192.43	-	-	-
	52.94	96.65	182.47	-	-	-
	47.72	98.61	177.29	-	-	-
	49.18	95.97	168.21	-	-	-
	48.06	97.78	185.20	-	-	-
	50.60	94.21	184.13	-	-	-
mean	51.92	100.03	185.57	-	-	-
StD	4.58	5.50	10.80	-	-	-

TABLE VIII (Continued)

temperature (C)	roller mill gap (mm) 0.3	0.5	0.7	hammer mill feed rate (kg/min) 17	29	whole seed
	BACK EXTRUSION PEAK FORCE (kg)					
5	8.30	12.60	12.50	-	-	-
	10.50	9.10	11.50	-	-	-
	8.50	9.70	12.50	-	-	-
	7.40	11.70	13.00	-	-	-
	9.20	9.50	12.50	-	-	-
	9.00	10.00	14.50	-	-	-
	9.10	10.00	11.00	-	-	-
	7.50	10.50	13.00	-	-	-
	9.80	11.80	10.00	-	-	-
	9.10	12.40	9.50	-	-	-
Mean	8.84	10.73	12.00	-	-	-
StD	0.96	1.28	1.51	-	-	-
20	8.60	14.00	13.50	14.00	29.50	53.60
	7.80	12.50	14.20	14.00	28.50	59.80
	8.50	10.00	15.00	17.00	33.00	47.00
	8.20	9.80	13.00	15.50	33.00	52.40
	7.20	12.50	11.50	14.50	28.00	50.50
	8.00	12.90	14.20	16.00	27.00	48.20
	8.50	10.50	12.80	14.00	29.00	54.40
	8.00	12.10	15.20	16.50	26.50	52.00
	10.00	10.50	15.80	13.00	20.50	45.20
	7.50	10.00	10.40	13.00	20.00	51.60
Mean	8.23	11.48	13.56	14.75	27.50	51.47
StD	0.77	1.49	1.69	1.42	4.40	4.14
35	9.10	9.80	14.20	-	-	-
	7.50	10.50	15.20	-	-	-
	8.50	11.00	16.20	-	-	-
	8.00	10.00	13.50	-	-	-
	7.50	10.50	10.50	-	-	-
	9.20	11.20	11.50	-	-	-
	7.00	11.40	12.00	-	-	-
	7.60	12.30	14.10	-	-	-
	8.00	10.10	13.20	-	-	-
	9.50	12.60	16.10	-	-	-
Mean	8.19	10.94	13.65	-	-	-
StD	0.85	0.95	1.91	-	-	-

TABLE VIII (Continued)

temperature (C)	roller mill gap (mm) 0.3	0.5	0.7	hammer mill feed rate (kg/min) 17	29	whole seed
	BACK EXTRUSION AVERAGE FORCE (kg)					
5	8.00	11.00	12.50	-	-	-
	9.50	11.00	13.00	-	-	-
	9.00	9.50	12.50	-	-	-
	8.50	11.00	13.00	-	-	-
	10.00	10.50	11.50	-	-	-
	9.50	11.00	13.50	-	-	-
	10.00	11.50	12.50	-	-	-
	7.50	10.00	11.50	-	-	-
	9.00	12.00	11.50	-	-	-
	10.00	11.00	11.00	-	-	-
Mean	9.10	10.85	12.25	-	-	-
StD	0.88	0.71	0.82	-	-	-
20	9.50	13.00	14.50	15.50	25.00	50.00
	9.00	12.00	14.50	16.00	25.50	52.00
	9.00	11.00	15.00	11.50	26.00	47.50
	8.50	8.00	15.00	16.00	25.00	54.00
	8.00	11.50	12.50	16.50	25.50	49.00
	8.00	12.00	13.00	16.50	25.50	46.00
	8.50	11.00	14.00	15.00	27.50	50.00
	8.50	13.00	14.50	16.50	25.50	49.00
	9.50	11.50	15.50	11.50	20.00	50.00
	9.50	10.50	14.00	13.00	18.00	51.00
Mean	8.80	11.35	14.25	14.80	24.35	49.85
StD	0.59	1.43	0.92	2.03	2.94	2.24
35	9.50	10.00	14.00	-	-	-
	8.00	12.00	15.00	-	-	-
	8.50	11.50	15.00	-	-	-
	8.50	11.50	14.50	-	-	-
	8.00	12.00	11.00	-	-	-
	8.50	10.50	13.00	-	-	-
	7.50	10.50	12.50	-	-	-
	9.00	12.00	12.00	-	-	-
	7.50	11.00	14.50	-	-	-
	9.50	12.50	15.00	-	-	-
Mean	8.45	11.35	13.65	-	-	-
StD	0.72	0.82	1.43	-	-	-

TABLE IX

DATA FOR FINE FRACTION

(in %)

temperature (C)	roller mill gap (mm) 0.3	0.5	0.7	hammer mill feed rate (kg/min) 17	29	whole seed
5	50.26	40.58	8.20	-	-	-
	46.78	40.61	9.10	-	-	-
	46.97	40.39	11.17	-	-	-
	44.95	45.75	10.91	-	-	-
	47.61	40.53	11.17	-	-	-
	47.42	41.12	11.77	-	-	-
Mean	47.33	41.50	10.39	-	-	-
StD	1.72	2.10	1.40	-	-	-
20	24.97	31.03	13.06	55.74	30.82	3.74
	29.33	26.37	10.39	56.51	30.16	3.98
	30.74	28.79	9.55	55.90	29.80	3.93
	35.18	21.00	12.44	56.20	26.29	-
	29.71	25.81	13.72	56.90	30.63	-
	31.58	20.86	14.01	54.62	32.10	-
Mean	30.25	25.64	12.20	55.98	29.97	3.88
StD	3.33	4.10	1.83	0.79	1.96	0.13
35	18.03	5.68	7.53	-	-	-
	21.69	5.97	7.97	-	-	-
	16.42	5.93	7.54	-	-	-
	23.23	5.59	7.08	-	-	-
	22.48	5.20	7.00	-	-	-
	22.69	5.49	8.41	-	-	-
Mean	20.76	5.64	7.59	-	-	-
StD	2.83	0.29	0.53	-	-	-

TABLE X

PARTICLE SIZE DISTRIBUTION PARAMETER CALCULATION

Roller Mill, Gap :0.3 mm
Temp.:5 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.06	0.031	0.18	0.10	99.94
#8	2.38	2.61	3.71	0.226	9.66	0.59	96.23
#10	2.00	2.19	21.87	0.939	47.90	2.06	74.36
#11	1.85	1.93	20.54	0.672	39.53	1.29	53.83
#12	1.68	1.77	6.50	0.161	11.47	0.28	47.33
#13	1.52	1.60	2.93	0.261	4.68	0.42	44.40
#14	1.41	1.47	7.76	0.254	11.36	0.37	36.65
#15	1.30	1.36	1.84	0.142	2.50	0.19	34.81
#16	1.19	1.25	3.72	0.246	4.64	0.31	31.08
#18	1.00	1.10	7.91	0.298	8.66	0.33	23.18
#20	0.84	0.92	6.30	0.361	5.80	0.33	16.88
#25	0.71	0.78	5.71	0.316	4.42	0.24	11.17
#30	0.59	0.65	4.73	0.408	3.08	0.27	6.44
#35	0.50	0.55	2.07	0.169	1.13	0.09	4.37
#40	0.42	0.46	1.34	0.104	0.62	0.05	3.03
#50	0.30	0.36	1.83	0.123	0.66	0.04	1.20
Pan	0.00	0.15	1.20	0.075	0.18	0.01	0.00
sum			100.00		156.44		
partial sum (#13-pan)			47.33				

Arithmetic mean size (mm): 1.564 (StD= 0.027)
Median size (mm): 1.750
Fine Fraction (%): 47.33 (StD= 1.72)

TABLE X (Continued)

Roller Mill, Gap :0.3 mm
Temp.:20 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.04	0.014	0.11	0.04	99.96
#8	2.38	2.61	5.73	0.594	14.93	1.55	94.23
#10	2.00	2.19	30.05	2.403	65.81	5.26	64.18
#11	1.85	1.93	25.68	0.436	49.43	0.84	38.51
#12	1.68	1.77	8.26	0.353	14.57	0.62	30.25
#13	1.52	1.60	2.92	0.155	4.67	0.25	27.33
#14	1.41	1.47	6.77	0.250	9.92	0.37	20.56
#15	1.30	1.36	1.67	0.259	2.27	0.35	18.89
#16	1.19	1.25	2.60	0.254	3.23	0.32	16.29
#18	1.00	1.10	4.81	0.354	5.27	0.39	11.48
#20	0.84	0.92	3.37	0.453	3.10	0.42	8.11
#25	0.71	0.78	3.02	0.565	2.34	0.44	5.09
#30	0.59	0.65	2.40	0.446	1.56	0.29	2.68
#35	0.50	0.55	0.86	0.225	0.47	0.12	1.83
#40	0.42	0.46	0.55	0.135	0.25	0.06	1.27
#50	0.30	0.36	0.76	0.216	0.27	0.08	0.51
Pan	0.00	0.15	0.51	0.112	0.08	0.02	0.00
sum			100.00	0.000	178.28		
partial sum (#13-pan)			30.252				

Arithmetic mean size (mm): 1.783 (StD= 0.057)
Median size (mm): 1.917
Fine Fraction (%): 30.25 (StD= 3.33)

TABLE X (Continued)

Roller Mill, Gap :0.3 mm
Temp.:35 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.03	0.013	0.08	0.04	99.98
#8	2.38	2.61	7.07	0.916	18.40	2.39	92.91
#10	2.00	2.19	34.26	1.688	75.03	3.70	58.65
#11	1.85	1.93	29.13	0.372	56.07	0.72	29.52
#12	1.68	1.77	8.76	0.335	15.47	0.59	20.76
#13	1.52	1.60	2.79	0.303	4.46	0.48	17.97
#14	1.41	1.47	6.31	0.281	9.24	0.41	11.66
#15	1.30	1.36	1.16	0.118	1.57	0.16	10.50
#16	1.19	1.25	1.56	0.322	1.94	0.40	8.94
#18	1.00	1.10	2.49	0.263	2.73	0.29	6.45
#20	0.84	0.92	1.97	0.443	1.81	0.41	4.49
#25	0.71	0.78	1.82	0.496	1.41	0.38	2.67
#30	0.59	0.65	1.12	0.290	0.73	0.19	1.55
#35	0.50	0.55	0.00	0.000	0.00	0.00	1.55
#40	0.42	0.46	0.00	0.000	0.00	0.00	1.55
#50	0.30	0.36	0.00	0.000	0.00	0.00	1.55
Pan	0.00	0.15	1.55	0.949	0.23	0.14	0.00
sum			100.00	0.000	189.17		
partial sum (#13-pan)			20.755				

Arithmetic mean size (mm): 1.892 (StD= 0.046)
Median size (mm): 1.955
Fine Fraction (%): 20.76 (StD= 2.83)

TABLE X (Continued)

Roller Mill, Gap :0.5 mm
Temp.:5 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.03	0.014	0.08	0.04	99.98
#8	2.38	2.61	3.14	0.149	8.18	0.39	96.83
#10	2.00	2.19	23.64	0.653	51.76	1.43	73.20
#11	1.85	1.93	23.93	1.034	46.06	1.99	49.27
#12	1.68	1.77	7.77	0.277	13.72	0.49	41.50
#13	1.52	1.60	3.27	0.440	5.23	0.70	38.23
#14	1.41	1.47	7.74	0.219	11.34	0.32	30.49
#15	1.30	1.36	1.79	0.048	2.42	0.07	28.70
#16	1.19	1.25	3.73	0.160	4.64	0.20	24.97
#18	1.00	1.10	6.90	0.149	7.56	0.16	18.07
#20	0.84	0.92	5.10	0.382	4.69	0.35	12.96
#25	0.71	0.78	4.46	0.510	3.46	0.40	8.50
#30	0.59	0.65	3.53	0.465	2.30	0.30	4.97
#35	0.50	0.55	1.48	0.293	0.81	0.16	3.49
#40	0.42	0.46	0.96	0.234	0.44	0.11	2.54
#50	0.30	0.36	1.51	0.349	0.54	0.13	1.03
Pan	0.00	0.15	1.03	0.223	0.15	0.03	0.00
sum			100.00	0.000	163.39		
partial sum (#13-pan)			41.498				

Arithmetic mean size (mm): 1.634 (StD= 0.027)
Median size (mm): 1.855
Fine Fraction (%): 41.50 (StD= 2.10)

TABLE X (Continued)

Roller Mill, Gap :0.5 mm
Temp.:20 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.03	1.401	0.10	4.34	99.97
#8	2.38	2.61	4.97	1.179	12.95	3.07	95.00
#10	2.00	2.19	31.08	2.616	68.07	5.73	63.91
#11	1.85	1.93	28.89	0.890	55.61	1.71	35.02
#12	1.68	1.77	9.38	0.542	16.56	0.96	25.64
#13	1.52	1.60	2.92	0.253	4.67	0.40	22.73
#14	1.41	1.47	6.78	0.256	9.94	0.38	15.94
#15	1.30	1.36	1.50	0.085	2.03	0.12	14.44
#16	1.19	1.25	2.37	0.355	2.95	0.44	12.07
#18	1.00	1.10	3.91	0.580	4.28	0.64	8.16
#20	0.84	0.92	2.50	0.628	2.30	0.58	5.66
#25	0.71	0.78	2.10	0.542	1.63	0.42	3.56
#30	0.59	0.65	1.63	0.548	1.06	0.36	1.94
#35	0.50	0.55	0.54	0.210	0.29	0.11	1.40
#40	0.42	0.46	0.39	0.186	0.18	0.09	1.01
#50	0.30	0.36	0.58	0.239	0.21	0.09	0.43
Pan	0.00	0.15	0.43	0.145	0.06	0.02	0.00
sum			100.00	0.000	182.89		
partial sum (#13-pan)			25.643				

Arithmetic mean size (mm): 1.829 (StD= 0.082)
Median size (mm): 1.928
Fine Fraction (%): 25.64 (StD= 4.100)

TABLE X (Continued)

Roller Mill, Gap :0.5 mm
Temp.:35 °C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.06	0.027	0.18	0.08	99.94
#8	2.38	2.61	7.80	0.624	20.32	1.63	92.14
#10	2.00	2.19	39.44	1.091	86.38	2.39	52.70
#11	1.85	1.93	36.88	0.788	71.00	1.52	15.82
#12	1.68	1.77	10.17	0.914	17.96	1.61	5.64
#13	1.52	1.60	2.17	0.227	3.47	0.36	3.48
#14	1.41	1.47	2.21	0.211	3.24	0.31	1.26
#15	1.30	1.36	0.14	0.013	0.19	0.02	1.12
#16	1.19	1.25	0.19	0.023	0.24	0.03	0.93
#18	1.00	1.10	0.25	0.035	0.28	0.04	0.68
#20	0.84	0.92	0.17	0.029	0.16	0.03	0.51
#25	0.71	0.78	0.17	0.029	0.13	0.02	0.34
#30	0.59	0.65	0.16	0.008	0.10	0.01	0.18
#35	0.50	0.55	0.00	0.000	0.00	0.00	0.18
#40	0.42	0.46	0.00	0.000	0.00	0.00	0.18
#50	0.30	0.36	0.00	0.000	0.00	0.00	0.18
Pan	0.00	0.15	0.18	0.033	0.03	0.00	0.00
sum			100.00	0.000	203.66		
partial sum (#13-pan)			5.641				

Arithmetic mean size (mm): 2.037 (StD= 0.037)
Median size (mm): 1.989
Fine Fraction (%): 5.64 (StD= 0.29)

TABLE X (Continued)

Roller Mill, Gap :0.7 mm
Temp.:5 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.05	0.019	0.16	0.06	99.95
#8	2.38	2.61	6.34	0.297	16.51	0.77	93.61
#10	2.00	2.19	36.27	1.089	79.42	2.38	57.34
#11	1.85	1.93	36.64	0.499	70.53	0.96	20.70
#12	1.68	1.77	10.31	0.384	18.20	0.68	10.39
#13	1.52	1.60	2.59	0.182	4.14	0.29	7.80
#14	1.41	1.47	3.79	0.482	5.55	0.71	4.02
#15	1.30	1.36	0.53	0.094	0.72	0.13	3.49
#16	1.19	1.25	0.68	0.112	0.85	0.14	2.80
#18	1.00	1.10	0.78	0.208	0.85	0.23	2.03
#20	0.84	0.92	0.54	0.124	0.50	0.11	1.48
#25	0.71	0.78	0.46	0.136	0.36	0.11	1.02
#30	0.59	0.65	0.00	0.000	0.00	0.00	1.02
#35	0.50	0.55	0.00	0.000	0.00	0.00	1.02
#40	0.42	0.46	0.00	0.000	0.00	0.00	1.02
#50	0.30	0.36	0.00	0.000	0.00	0.00	1.02
Pan	0.00	0.15	1.02	0.407	0.15	0.06	0.00
sum			100.00	0.000	197.95		
partial sum (#13-pan)			10.388				

Arithmetic mean size (mm): 1.979 (StD= 0.029)
Median size (mm): 1.970
Fine Fraction (%): 10.39 (StD= 1.40)

TABLE X (Continued)

Roller Mill, Gap :0.7 mm
Temp.:20 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.00	0.000	0.00	0.00	100.00
#8	2.38	2.61	7.89	0.678	20.54	1.77	92.11
#10	2.00	2.19	37.16	1.732	81.38	3.79	54.95
#11	1.85	1.93	32.80	0.869	63.15	1.67	22.15
#12	1.68	1.77	9.96	0.485	17.57	0.86	12.20
#13	1.52	1.60	2.50	0.228	4.00	0.36	9.70
#14	1.41	1.47	4.08	0.234	5.97	0.34	5.62
#15	1.30	1.36	0.85	0.083	1.15	0.11	4.77
#16	1.19	1.25	0.94	0.132	1.16	0.16	3.84
#18	1.00	1.10	1.29	0.238	1.42	0.26	2.54
#20	0.84	0.92	0.81	0.214	0.74	0.20	1.73
#25	0.71	0.78	0.68	0.224	0.52	0.17	1.06
#30	0.59	0.65	0.47	0.188	0.31	0.12	0.58
#35	0.50	0.55	0.00	0.000	0.00	0.00	0.58
#40	0.42	0.46	0.00	0.000	0.00	0.00	0.58
#50	0.30	0.36	0.00	0.000	0.00	0.00	0.58
Pan	0.00	0.15	0.58	0.299	0.09	0.04	0.00
sum			100.00	0.000	198.00		
partial sum (#13-pan)			12.196				

Arithmetic mean size (mm): 1.980 (StD= 0.046)
Median size (mm): 1.977
Fine Fraction (%): 12.20 (StD= 1.83)

TABLE X (Continued)

Roller Mill, Gap :0.7 mm
Temp.:35 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.00	0.000	0.00	0.00	100.00
#8	2.38	2.61	7.21	0.435	18.77	1.13	92.79
#10	2.00	2.19	37.52	0.896	82.16	1.96	55.28
#11	1.85	1.93	37.17	0.816	71.55	1.57	18.11
#12	1.68	1.77	10.52	0.506	18.57	0.89	7.59
#13	1.52	1.60	2.47	0.226	3.95	0.36	5.12
#14	1.41	1.47	2.87	0.286	4.20	0.42	2.25
#15	1.30	1.36	0.39	0.034	0.53	0.05	1.86
#16	1.19	1.25	0.41	0.093	0.51	0.12	1.45
#18	1.00	1.10	0.49	0.055	0.54	0.06	0.95
#20	0.84	0.92	0.28	0.031	0.25	0.03	0.68
#25	0.71	0.78	0.25	0.051	0.19	0.04	0.43
#30	0.59	0.65	0.21	0.069	0.14	0.04	0.22
#35	0.50	0.55	0.00	0.000	0.00	0.00	0.22
#40	0.42	0.46	0.00	0.000	0.00	0.00	0.22
#50	0.30	0.36	0.00	0.000	0.00	0.00	0.22
0.00	0.00	0.15	0.22	0.087	0.03	0.01	0.00
sum			100.00	0.000	201.41		
partial sum (#13-pan)			7.588				

Arithmetic mean size (mm): 2.014 (StD= 0.030)
Median size (mm): 1.979
Fine Fraction (%): 7.59 (StD= 0.53)

TABLE X (Continued)

Hammer Mill, Feed Rate:17 kg/min
Temp.:20 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.00	0.000	0.00	0.00	100.00
#8	2.38	2.61	1.65	0.119	4.30	0.31	98.35
#10	2.00	2.19	15.31	0.371	33.52	0.81	83.04
#11	1.85	1.93	19.89	0.955	38.29	1.84	63.15
#12	1.68	1.77	7.18	0.624	12.66	1.10	55.98
#13	1.52	1.60	2.29	0.292	3.67	0.47	53.68
#14	1.41	1.47	11.11	0.373	16.27	0.55	42.58
#15	1.30	1.36	3.99	0.231	5.40	0.31	38.59
#16	1.19	1.25	7.14	0.237	8.89	0.30	31.44
#18	1.00	1.10	9.40	0.151	10.29	0.17	22.05
#20	0.84	0.92	5.52	0.205	5.08	0.19	16.53
#25	0.71	0.78	5.66	0.264	4.38	0.20	10.87
#30	0.59	0.65	5.02	0.342	3.26	0.22	5.85
#35	0.50	0.55	1.97	0.136	1.07	0.07	3.89
#40	0.42	0.46	1.09	0.076	0.50	0.03	2.79
#50	0.30	0.36	1.37	0.122	0.49	0.04	1.43
Pan	0.00	0.15	1.43	0.137	0.21	0.02	0.00
sum			100.00	0.000	148.30		
partial sum (#13-pan)			55.977				

Arithmetic mean size (mm): 1.483 (StD= 0.025)
Median size (mm): 1.484
Fine Fraction (%): 55.98 (StD= 0.79)

TABLE X (Continued)

Hammer Mill, Feed Rate: 29 kg/min
Temp.:20 C

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.00	0.007	0.01	0.02	100.00
#8	2.38	2.61	3.20	0.165	8.32	0.43	96.80
#10	2.00	2.19	26.34	1.258	57.69	2.76	70.46
#11	1.85	1.93	30.74	0.611	59.17	1.18	39.73
#12	1.68	1.77	9.76	0.298	17.22	0.53	29.97
#13	1.52	1.60	2.45	0.167	3.92	0.27	27.52
#14	1.41	1.47	6.22	0.169	9.11	0.25	21.30
#15	1.30	1.36	1.89	0.068	2.56	0.09	19.41
#16	1.19	1.25	2.87	0.108	3.57	0.13	16.54
#18	1.00	1.10	4.55	0.206	4.98	0.23	11.99
#20	0.84	0.92	2.41	0.241	2.21	0.22	9.58
#25	0.71	0.78	2.76	0.228	2.14	0.18	6.82
#30	0.59	0.65	2.65	0.404	1.72	0.26	4.17
#35	0.50	0.55	1.20	0.169	0.66	0.09	2.97
#40	0.42	0.46	0.76	0.119	0.35	0.05	2.21
#50	0.30	0.36	1.08	0.198	0.39	0.07	1.13
Pan	0.00	0.15	1.13	0.180	0.17	0.03	0.00
sum			100.00	0.000	174.19		
partial sum (#13-pan)			29.966				

Arithmetic mean size (mm): 1.742 (StD= 0.031)
Median size (mm): 1.900
Fine Fraction (%): 29.97 (StD= 1.96)

TABLE X (Continued)

Whole mustard seed used for roller milling

sieve No.	sieve opening (mm)	nominal particle size (mm)	freq. (%)	StD (%)	(3)x(4) (%)	StD (3)x(5) (%)	total passed (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
#6	3.36						
#7	2.83	3.10	0.00	0.000	0.00	0.00	100.00
#8	2.38	2.61	5.14	0.325	13.40	0.85	94.86
#10	2.00	2.19	38.40	0.578	84.10	1.27	56.45
#11	1.85	1.93	40.91	1.141	78.75	2.20	15.54
#12	1.68	1.77	11.66	0.735	20.58	1.30	3.88
#13	1.52	1.60	2.21	0.109	3.53	0.17	1.67
#14	1.41	1.47	1.65	0.026	2.41	0.04	0.03
#15	1.30	1.36	0.03	0.009	0.04	0.01	0.00
#16	1.19	1.25	0.00	0.000	0.00	0.00	0.00
#18	1.00	1.10	0.00	0.000	0.00	0.00	0.00
#20	0.84	0.92	0.00	0.000	0.00	0.00	0.00
#25	0.71	0.78	0.00	0.000	0.00	0.00	0.00
#30	0.59	0.65	0.00	0.000	0.00	0.00	0.00
#35	0.50	0.55	0.00	0.000	0.00	0.00	0.00
#40	0.42	0.46	0.00	0.000	0.00	0.00	0.00
#50	0.30	0.36	0.00	0.000	0.00	0.00	0.00
Pan	0.00	0.15	0.00	0.000	0.00	0.00	0.00
sum			100.00	0.000	202.82		
partial sum (#13-pan)			3.8816				

Arithmetic mean size (mm): 2.028 (StD= 0.030)
Median size (mm): 1.976
Fine Fraction (%): 3.88 (StD= 0.13)

TABLE XI

PARTICLE SIZE DISTRIBUTION BY WEIGHT

Roller Mill, Gap :0.3 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.01	0.10	0.04	0.09	0.05	0.06	0.06	0.030
#8	2.51	3.50	3.56	3.96	3.48	4.05	3.49	3.67	0.237
#10	2.00	19.91	21.77	21.82	23.33	21.62	21.53	21.66	0.992
#11	1.85	18.92	20.05	20.40	21.22	20.22	21.24	20.34	0.786
#12	1.68	6.41	6.27	6.64	6.68	6.35	6.25	6.43	0.169
#13	1.52	2.92	2.93	2.54	3.20	2.60	3.19	2.90	0.257
#14	1.41	7.59	7.58	8.10	7.65	7.88	7.28	7.68	0.257
#15	1.30	1.54	1.88	1.84	1.93	1.77	2.00	1.83	0.147
#16	1.19	4.07	3.43	3.66	3.36	3.83	3.77	3.69	0.241
#18	1.00	8.21	7.82	8.04	7.82	7.55	7.52	7.83	0.246
#20	0.84	6.82	6.14	6.41	5.73	6.17	6.16	6.24	0.328
#25	0.71	6.12	5.47	5.41	5.25	5.78	5.88	5.65	0.300
#30	0.59	5.10	4.12	4.73	4.12	5.05	5.00	4.69	0.417
#35	0.50	2.31	1.96	1.98	1.79	2.12	2.12	2.05	0.162
#40	0.42	1.41	1.27	1.25	1.17	1.46	1.41	1.33	0.104
#50	0.30	1.90	1.75	1.70	1.65	2.00	1.88	1.81	0.123
Pan	0.00	1.26	1.13	1.16	1.08	1.30	1.20	1.19	0.075
sum		98.00	97.23	99.68	99.55	99.80	99.98	99.04	1.040

TABLE XI (Continued)

Roller Mill, Gap :0.3 mm
Temp.:20 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.03	0.05	0.02	0.05	0.05	0.02	0.04	0.014
#8	2.51	6.86	5.81	5.35	5.06	5.80	5.35	5.71	0.581
#10	2.00	34.10	29.54	30.77	26.06	29.50	29.53	29.92	2.365
#11	1.85	25.38	25.83	25.03	25.62	26.27	25.25	25.56	0.406
#12	1.68	8.12	8.85	8.08	7.81	8.44	8.02	8.22	0.337
#13	1.52	2.64	2.98	2.95	2.79	2.93	3.14	2.91	0.156
#14	1.41	6.67	6.70	6.63	7.28	6.66	6.50	6.74	0.250
#15	1.30	1.28	1.61	1.39	1.88	1.92	1.92	1.67	0.259
#16	1.19	2.10	2.60	2.79	2.79	2.43	2.81	2.59	0.256
#18	1.00	4.11	4.70	4.89	5.32	4.84	4.89	4.79	0.359
#20	0.84	2.61	3.12	3.33	4.07	3.31	3.70	3.36	0.455
#25	0.71	2.05	2.80	3.12	3.96	2.93	3.20	3.01	0.566
#30	0.59	1.73	2.22	2.51	3.22	2.22	2.45	2.39	0.447
#35	0.50	0.53	0.72	0.90	1.27	0.80	0.91	0.86	0.225
#40	0.42	0.33	0.52	0.66	0.74	0.45	0.59	0.55	0.135
#50	0.30	0.42	0.64	0.95	1.08	0.66	0.81	0.76	0.216
Pan	0.00	0.32	0.47	0.62	0.66	0.46	0.54	0.51	0.112
sum		99.28	99.16	99.99	99.66	99.67	99.63	99.57	0.274

TABLE XI (Continued)

Roller Mill, Gap :0.3 mm
Temp.:35 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.02	0.03	0.03	0.04	0.03	0.00	0.03	0.013
#8	2.51	8.05	6.72	8.39	6.58	6.00	6.47	7.04	0.872
#10	2.00	35.76	32.99	36.33	32.04	34.52	33.17	34.14	1.540
#11	1.85	29.30	29.10	28.62	29.67	28.63	28.84	29.03	0.377
#12	1.68	8.68	9.38	8.75	8.28	8.60	8.70	8.73	0.328
#13	1.52	2.59	2.96	2.53	3.30	2.91	2.39	2.78	0.308
#14	1.41	6.20	6.60	5.85	6.20	6.12	6.74	6.29	0.299
#15	1.30	0.98	1.20	1.08	1.13	1.38	1.15	1.15	0.122
#16	1.19	1.38	2.08	1.46	1.28	1.23	1.91	1.56	0.322
#18	1.00	2.08	2.69	2.18	2.84	2.58	2.53	2.48	0.270
#20	0.84	1.53	2.07	1.23	2.44	2.46	2.04	1.96	0.450
#25	0.71	1.89	1.75	0.81	2.35	1.83	2.25	1.81	0.499
#30	0.59	0.87	1.35	0.58	1.23	1.39	1.28	1.12	0.294
#35	0.50	-	-	-	-	-	-	-	-
#40	0.42	-	-	-	-	-	-	-	-
#50	0.30	-	-	-	-	-	-	-	-
Pan	0.00	0.47	0.97	0.41	2.41	2.66	2.36	1.55	0.951
sum		99.80	99.89	98.25	99.79	100.34	99.83	99.65	0.654

TABLE XI (Continued)

Roller Mill, Gap :0.5 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.02	0.02	0.03	0.04	0.00	0.04	0.03	0.014
#8	2.51	3.13	3.28	3.15	2.93	2.94	3.33	3.13	0.152
#10	2.00	23.56	23.78	24.31	22.13	23.66	23.66	23.52	0.666
#11	1.85	24.33	24.23	24.27	21.51	24.59	23.91	23.81	1.046
#12	1.68	8.10	7.87	7.52	7.25	7.94	7.72	7.73	0.281
#13	1.52	3.56	3.34	3.43	2.28	3.50	3.40	3.25	0.440
#14	1.41	7.54	8.08	7.58	7.49	7.94	7.60	7.71	0.222
#15	1.30	1.78	1.74	1.84	1.80	1.70	1.82	1.78	0.048
#16	1.19	3.75	3.82	3.91	3.63	3.73	3.41	3.71	0.158
#18	1.00	6.74	6.88	6.63	6.95	6.90	7.10	6.87	0.150
#20	0.84	4.95	4.96	4.72	5.89	4.92	5.02	5.08	0.376
#25	0.71	4.20	4.14	4.27	5.55	4.12	4.36	4.44	0.503
#30	0.59	3.25	3.22	3.38	4.53	3.31	3.39	3.51	0.459
#35	0.50	1.36	1.31	1.31	2.10	1.26	1.48	1.47	0.290
#40	0.42	0.95	0.76	0.81	1.45	0.85	0.88	0.95	0.231
#50	0.30	1.33	1.34	1.38	2.26	1.24	1.46	1.50	0.345
Pan	0.00	0.98	0.88	0.90	1.49	0.83	1.05	1.02	0.221
sum		99.53	99.65	99.44	99.28	99.43	99.63	99.49	0.127

TABLE XI (Continued)

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
Roller Mill,	Gap :0.5 mm Temp.:20 C								
#7	2.82	0.03	0.02	0.03	0.04	0.03	0.04	0.03	0.007
#8	2.51	4.12	5.04	4.57	6.25	4.46	5.30	4.96	0.694
#10	2.00	26.51	31.18	29.03	34.51	31.63	33.09	30.99	2.619
#11	1.85	28.00	27.90	27.99	28.84	29.48	30.62	28.81	0.990
#12	1.68	9.90	9.31	9.45	8.91	8.49	10.06	9.35	0.540
#13	1.52	3.20	3.05	3.14	2.84	2.49	2.72	2.91	0.250
#14	1.41	7.06	6.65	6.97	6.32	6.95	6.63	6.76	0.256
#15	1.30	1.56	1.36	1.42	1.48	1.59	1.57	1.50	0.085
#16	1.19	2.82	2.41	2.75	2.10	2.28	1.81	2.36	0.352
#18	1.00	4.78	4.01	4.38	3.19	3.79	3.23	3.90	0.575
#20	0.84	3.36	2.50	3.09	1.79	2.60	1.64	2.50	0.625
#25	0.71	2.82	2.31	2.44	1.39	2.22	1.36	2.09	0.539
#30	0.59	2.47	1.69	2.03	0.95	1.62	0.96	1.62	0.545
#35	0.50	0.76	0.56	0.74	0.24	0.64	0.27	0.54	0.209
#40	0.42	0.62	0.46	0.53	0.13	0.44	0.15	0.39	0.185
#50	0.30	0.82	0.75	0.73	0.25	0.69	0.25	0.58	0.238
Pan	0.00	0.57	0.55	0.52	0.20	0.46	0.26	0.43	0.144
sum		99.40	99.75	99.81	99.43	99.86	99.96	99.70	0.212

TABLE XI (Continued)

Roller Mill, Gap :0.5 mm
Temp.:35 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.06	0.04	0.07	0.03	0.11	0.04	0.06	0.027
#8	2.51	7.54	8.16	6.77	8.69	8.18	7.36	7.78	0.631
#10	2.00	41.10	37.58	38.43	39.37	40.30	39.36	39.36	1.151
#11	1.85	35.49	37.05	36.47	37.01	36.65	38.12	36.80	0.785
#12	1.68	10.00	10.76	11.82	9.24	9.59	9.49	10.15	0.891
#13	1.52	2.37	2.27	2.37	1.73	2.19	2.04	2.16	0.224
#14	1.41	2.08	2.45	2.21	2.50	1.91	2.10	2.21	0.208
#15	1.30	0.13	0.16	0.15	0.14	0.12	0.14	0.14	0.013
#16	1.19	0.18	0.20	0.19	0.15	0.22	0.21	0.19	0.023
#18	1.00	0.25	0.22	0.26	0.29	0.20	0.30	0.25	0.035
#20	0.84	0.19	0.18	0.19	0.20	0.13	0.13	0.17	0.029
#25	0.71	0.14	0.17	0.18	0.21	0.12	0.17	0.17	0.029
#30	0.59	0.16	0.15	0.17	0.17	0.16	0.15	0.16	0.008
#35	0.50	-	-	-	-	-	-	-	-
#40	0.42	-	-	-	-	-	-	-	-
#50	0.30	-	-	-	-	-	-	-	-
Pan	0.00	0.17	0.14	0.18	0.20	0.15	0.24	0.18	0.033
sum		99.86	99.53	99.46	99.93	100.03	99.85	99.78	0.209

TABLE XI (Continued)

Roller Mill, Gap :0.7 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.05	0.08	0.07	0.06	0.03	0.03	0.05	0.019
#8	2.51	6.81	6.53	5.96	6.11	6.46	6.14	6.34	0.291
#10	2.00	37.87	37.10	34.79	36.44	36.16	35.09	36.24	1.070
#11	1.85	37.39	36.41	37.15	36.27	35.90	36.58	36.62	0.510
#12	1.68	9.62	10.53	10.86	10.34	10.08	10.40	10.31	0.385
#13	1.52	2.78	2.68	2.22	2.62	2.51	2.69	2.58	0.182
#14	1.41	3.31	3.15	4.49	3.63	3.83	4.29	3.78	0.484
#15	1.30	0.38	0.47	0.55	0.50	0.61	0.67	0.53	0.094
#16	1.19	0.45	0.67	0.78	0.78	0.73	0.69	0.68	0.112
#18	1.00	0.36	0.65	0.93	0.91	0.90	0.90	0.78	0.209
#20	0.84	0.31	0.45	0.59	0.62	0.66	0.63	0.54	0.123
#25	0.71	0.27	0.35	0.58	0.37	0.57	0.63	0.46	0.136
#30	0.59	-	-	-	-	-	-	-	-
#35	0.50	-	-	-	-	-	-	-	-
#40	0.42	-	-	-	-	-	-	-	-
#50	0.30	-	-	-	-	-	-	-	-
Pan	0.00	0.34	0.65	1.03	1.50	1.34	1.27	1.02	0.407
sum		99.94	99.72	100.00	100.15	99.78	100.01	99.93	0.145

TABLE XI (Continued)

Roller Mill, Gap :0.7 mm
Temp.:20 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	-	-	-	-	-	-	-	-
#8	2.51	8.21	8.78	8.52	7.22	7.56	6.95	7.87	0.675
#10	2.00	38.32	39.27	38.51	36.57	34.65	35.28	37.10	1.721
#11	1.85	31.43	31.76	32.90	33.29	33.66	33.46	32.75	0.853
#12	1.68	9.12	9.44	10.34	10.30	10.28	10.15	9.94	0.478
#13	1.52	2.51	2.20	2.25	2.45	2.82	2.74	2.50	0.229
#14	1.41	4.19	4.05	3.58	4.32	4.09	4.18	4.07	0.234
#15	1.30	0.90	0.78	0.77	0.77	0.99	0.89	0.85	0.083
#16	1.19	0.87	0.78	0.77	1.05	1.04	1.09	0.93	0.131
#18	1.00	1.43	1.06	0.91	1.27	1.54	1.54	1.29	0.239
#20	0.84	0.84	0.54	0.52	0.84	1.08	1.02	0.81	0.214
#25	0.71	0.85	0.42	0.33	0.71	0.94	0.80	0.68	0.224
#30	0.59	0.62	0.26	0.19	0.47	0.61	0.69	0.47	0.188
#35	0.50	-	-	-	-	-	-	-	-
#40	0.42	-	-	-	-	-	-	-	-
#50	0.30	-	-	-	-	-	-	-	-
Pan	0.00	0.87	0.26	0.21	0.53	0.59	1.04	0.58	0.299
sum		100.16	99.60	99.80	99.79	99.85	99.83	99.84	0.165

TABLE XI (Continued)

Roller Mill, Gap :0.7 mm Temp.:35 C									
sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	-	-	-	-	-	-	-	-
#8	2.51	6.85	7.68	7.33	7.47	7.28	6.41	7.17	0.422
#10	2.00	37.94	36.16	38.02	38.32	36.05	37.47	37.33	0.900
#11	1.85	36.31	36.58	36.51	36.16	38.33	38.00	36.98	0.853
#12	1.68	10.85	10.96	10.11	10.41	10.86	9.60	10.47	0.488
#13	1.52	2.83	2.60	2.48	2.39	2.33	2.12	2.46	0.221
#14	1.41	2.59	2.78	2.70	2.67	2.91	3.46	2.85	0.290
#15	1.30	0.35	0.44	0.43	0.39	0.36	0.38	0.39	0.033
#16	1.19	0.39	0.43	0.38	0.31	0.34	0.60	0.41	0.094
#18	1.00	0.55	0.54	0.47	0.45	0.40	0.53	0.49	0.054
#20	0.84	0.27	0.31	0.28	0.26	0.22	0.31	0.28	0.031
#25	0.71	0.21	0.30	0.26	0.23	0.17	0.32	0.25	0.051
#30	0.59	0.18	0.23	0.26	0.16	0.11	0.32	0.21	0.069
#35	0.50	-	-	-	-	-	-	-	-
#40	0.42	-	-	-	-	-	-	-	-
#50	0.30	-	-	-	-	-	-	-	-
Pan	0.00	0.12	0.28	0.24	0.18	0.12	0.36	0.22	0.087
sum		99.44	99.29	99.47	99.40	99.48	99.88	99.49	0.184

TABLE XI (Continued)

Hammer Mill, Feed Rate: 17 kg/min
Temp.:20 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#8	2.51	1.48	1.53	1.80	1.58	1.74	1.71	1.64	0.117
#10	2.00	15.41	15.36	15.78	14.63	14.96	15.04	15.20	0.368
#11	1.85	19.00	19.37	19.65	19.52	19.14	21.82	19.75	0.951
#12	1.68	8.21	6.88	6.48	7.70	6.94	6.54	7.13	0.627
#13	1.52	2.39	2.07	1.93	2.58	2.01	2.69	2.28	0.291
#14	1.41	11.32	11.64	10.63	10.65	10.75	11.18	11.03	0.379
#15	1.30	3.88	4.41	3.74	3.78	3.86	4.09	3.96	0.230
#16	1.19	7.33	6.88	7.07	7.26	7.32	6.70	7.09	0.237
#18	1.00	9.19	9.10	9.41	9.33	9.53	9.41	9.33	0.145
#20	0.84	5.11	5.66	5.64	5.58	5.55	5.35	5.48	0.194
#25	0.71	6.05	5.30	5.69	5.47	5.83	5.35	5.62	0.268
#30	0.59	4.54	5.16	4.98	5.19	5.46	4.57	4.98	0.334
#35	0.50	2.02	1.90	2.03	2.02	2.08	1.68	1.96	0.134
#40	0.42	1.04	1.07	1.15	1.14	1.16	0.95	1.09	0.075
#50	0.30	1.34	1.37	1.53	1.34	1.42	1.13	1.35	0.120
Pan	0.00	1.33	1.49	1.60	1.38	1.51	1.19	1.42	0.134
sum		99.64	99.19	99.11	99.15	99.26	99.40	99.29	0.181

TABLE XI (Continued)

Hammer Mill, Feed Rate:29 kg/min.
Temp.:20 C

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	4	5	6	mean (gram)	Std (gram)
#7	2.82	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.007
#8	2.51	3.02	3.08	3.29	3.50	3.03	3.21	3.19	0.170
#10	2.00	26.45	26.06	26.23	28.72	25.81	24.43	26.28	1.270
#11	1.85	29.98	30.03	30.94	31.94	30.79	30.34	30.67	0.670
#12	1.68	9.34	10.27	9.56	9.63	9.71	9.91	9.74	0.293
#13	1.52	2.29	2.36	2.41	2.36	2.81	2.45	2.45	0.170
#14	1.41	6.38	6.21	6.18	6.27	5.87	6.31	6.20	0.163
#15	1.30	1.93	1.86	1.91	1.92	1.75	1.95	1.89	0.067
#16	1.19	2.93	2.88	2.78	2.71	2.83	3.04	2.86	0.106
#18	1.00	4.61	4.61	4.69	4.12	4.50	4.71	4.54	0.200
#20	0.84	2.53	2.37	2.26	1.97	2.56	2.71	2.40	0.239
#25	0.71	2.62	2.83	2.85	2.33	2.85	3.05	2.76	0.227
#30	0.59	2.82	2.64	2.50	1.88	2.86	3.18	2.65	0.402
#35	0.50	1.27	1.21	1.18	0.85	1.34	1.35	1.20	0.168
#40	0.42	0.84	0.77	0.70	0.52	0.83	0.87	0.76	0.119
#50	0.30	1.20	1.12	1.09	0.65	1.22	1.19	1.08	0.197
Pan	0.00	1.23	1.13	1.17	0.74	1.20	1.28	1.13	0.178
sum		99.44	99.45	99.74	100.11	99.96	99.98	99.78	0.261

TABLE XI (Continued)

Whole mustard seed used for roller milling

sieve No.	sieve opening size (mm)	sieve weight on each sieve (gram) 1	2	3	mean (gram)	Std (gram)
#7	2.82	8.00	0.00	0.00	0.00	0.000
#8	2.51	4.72	5.15	5.49	5.12	0.315
#10	2.00	37.57	38.30	38.80	38.22	0.505
#11	1.85	41.74	41.33	39.09	40.72	1.165
#12	1.68	12.10	10.55	12.18	11.61	0.750
#13	1.52	2.05	2.26	2.28	2.20	0.104
#14	1.41	1.64	1.67	1.61	1.64	0.024
#15	1.30	0.04	0.02	0.02	0.03	0.009
#16	1.19	0.00	0.00	0.00	0.00	0.000
#18	1.00	-	-	-	-	-
#20	0.84	-	-	-	-	-
#25	0.71	-	-	-	-	-
#30	0.59	-	-	-	-	-
#35	0.50	-	-	-	-	-
#40	0.42	-	-	-	-	-
#50	0.30	-	-	-	-	-
Pan	0.00	-	-	-	-	-
sum		99.86	99.28	99.47	99.54	0.241

TABLE XII

PARTICLE SIZE DISTRIBUTION BY FREQUENCY

Roller Mill, Gap :0.3 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.01	0.10	0.04	0.09	0.05	0.06	0.06	0.031
#8	2.38	3.57	3.66	3.97	3.50	4.06	3.49	3.71	0.226
#10	2.00	20.32	22.39	21.89	23.44	21.66	21.53	21.87	0.939
#11	1.85	19.31	20.62	20.47	21.32	20.26	21.24	20.54	0.672
#12	1.68	6.54	6.45	6.66	6.71	6.36	6.25	6.50	0.161
#13	1.52	2.98	3.01	2.55	3.21	2.61	3.19	2.93	0.261
#14	1.41	7.74	7.80	8.13	7.68	7.90	7.28	7.76	0.254
#15	1.30	1.57	1.93	1.85	1.94	1.77	2.00	1.84	0.142
#16	1.19	4.15	3.53	3.67	3.38	3.84	3.77	3.72	0.246
#18	1.00	8.38	8.04	8.07	7.86	7.57	7.52	7.91	0.298
#20	0.84	6.96	6.31	6.43	5.76	6.18	6.16	6.30	0.361
#25	0.71	6.24	5.63	5.43	5.27	5.79	5.88	5.71	0.316
#30	0.59	5.20	4.24	4.75	4.14	5.06	5.00	4.73	0.408
#35	0.50	2.36	2.02	1.99	1.80	2.12	2.12	2.07	0.169
#40	0.42	1.44	1.31	1.25	1.18	1.46	1.41	1.34	0.104
#50	0.30	1.94	1.80	1.71	1.66	2.00	1.88	1.83	0.123
Pan	0.00	1.29	1.16	1.16	1.08	1.30	1.20	1.20	0.075
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		50.26	46.78	46.97	44.95	47.61	47.42	47.33	1.720

TABLE XII (Continued)

Roller Mill, Gap :0.3 mm
Temp.:20 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.03	0.05	0.02	0.05	0.05	0.02	0.04	0.014
#8	2.38	6.91	5.86	5.35	5.08	5.82	5.37	5.73	0.594
#10	2.00	34.35	29.79	30.77	26.15	29.60	29.64	30.05	2.403
#11	1.85	25.56	26.05	25.03	25.71	26.36	25.34	25.68	0.436
#12	1.68	8.18	8.92	8.08	7.84	8.47	8.05	8.26	0.353
#13	1.52	2.66	3.01	2.95	2.80	2.94	3.15	2.92	0.155
#14	1.41	6.72	6.76	6.63	7.30	6.68	6.52	6.77	0.250
#15	1.30	1.29	1.62	1.39	1.89	1.93	1.93	1.67	0.259
#16	1.19	2.12	2.62	2.79	2.80	2.44	2.82	2.60	0.254
#18	1.00	4.14	4.74	4.89	5.34	4.86	4.91	4.81	0.354
#20	0.84	2.63	3.15	3.33	4.08	3.32	3.71	3.37	0.453
#25	0.71	2.06	2.82	3.12	3.97	2.94	3.21	3.02	0.565
#30	0.59	1.74	2.24	2.51	3.23	2.23	2.46	2.40	0.446
#35	0.50	0.53	0.73	0.90	1.27	0.80	0.91	0.86	0.225
#40	0.42	0.33	0.52	0.66	0.74	0.45	0.59	0.55	0.135
#50	0.30	0.42	0.65	0.95	1.08	0.66	0.81	0.76	0.216
Pan	0.00	0.32	0.47	0.62	0.66	0.46	0.54	0.51	0.112
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		24.97	29.33	30.74	35.18	29.71	31.58	30.25	3.330

TABLE XII (Continued)

Roller Mill, Gap :0.3 mm
Temp.:35 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.02	0.03	0.03	0.04	0.03	0.00	0.03	0.013
#8	2.38	8.07	6.73	8.54	6.59	5.98	6.48	7.07	0.916
#10	2.00	35.83	33.03	36.98	32.11	34.40	33.23	34.26	1.688
#11	1.85	29.36	29.13	29.13	29.73	28.53	28.89	29.13	0.372
#12	1.68	8.70	9.39	8.91	8.30	8.57	8.71	8.76	0.335
#13	1.52	2.60	2.96	2.58	3.31	2.90	2.39	2.79	0.303
#14	1.41	6.21	6.61	5.95	6.21	6.10	6.75	6.31	0.281
#15	1.30	0.98	1.20	1.10	1.13	1.38	1.15	1.16	0.118
#16	1.19	1.38	2.08	1.49	1.28	1.23	1.91	1.56	0.322
#18	1.00	2.08	2.69	2.22	2.85	2.57	2.53	2.49	0.263
#20	0.84	1.53	2.07	1.25	2.45	2.45	2.04	1.97	0.443
#25	0.71	1.89	1.75	0.82	2.35	1.82	2.25	1.82	0.496
#30	0.59	0.87	1.35	0.59	1.23	1.39	1.28	1.12	0.290
#35	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.47	0.97	0.42	2.42	2.65	2.36	1.55	0.949
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		18.03	21.69	16.42	23.23	22.48	22.69	20.76	2.830

TABLE XII (Continued)

Roller Mill, Gap :0.5 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.02	0.02	0.03	0.04	0.00	0.04	0.03	0.014
#8	2.38	3.14	3.29	3.17	2.95	2.96	3.34	3.14	0.149
#10	2.00	23.67	23.86	24.45	22.29	23.80	23.75	23.64	0.653
#11	1.85	24.44	24.32	24.41	21.67	24.73	24.00	23.93	1.034
#12	1.68	8.14	7.90	7.56	7.30	7.99	7.75	7.77	0.277
#13	1.52	3.58	3.35	3.45	2.30	3.52	3.41	3.27	0.440
#14	1.41	7.58	8.11	7.62	7.54	7.99	7.63	7.74	0.219
#15	1.30	1.79	1.75	1.85	1.81	1.71	1.83	1.79	0.048
#16	1.19	3.77	3.83	3.93	3.66	3.75	3.42	3.73	0.160
#18	1.00	6.77	6.90	6.67	7.00	6.94	7.13	6.90	0.149
#20	0.84	4.97	4.98	4.75	5.93	4.95	5.04	5.10	0.382
#25	0.71	4.22	4.15	4.29	5.59	4.14	4.38	4.46	0.510
#30	0.59	3.27	3.23	3.40	4.56	3.33	3.40	3.53	0.465
#35	0.50	1.37	1.31	1.32	2.12	1.27	1.49	1.48	0.293
#40	0.42	0.95	0.76	0.81	1.46	0.85	0.88	0.96	0.234
#50	0.30	1.34	1.34	1.39	2.28	1.25	1.47	1.51	0.349
Pan	0.00	0.98	0.88	0.91	1.50	0.83	1.05	1.03	0.223
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		40.58	40.61	40.39	45.75	40.53	41.12	41.50	2.100

TABLE XII (Continued)

Roller Mill, Gap :0.5 mm
Temp.:20 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.03	0.02	0.03	0.04	0.03	0.04	0.03	0.007
#8	2.38	4.14	5.05	4.58	6.29	4.47	5.30	4.97	0.701
#10	2.00	26.67	31.26	29.09	34.71	31.67	33.10	31.08	2.616
#11	1.85	28.17	27.97	28.04	29.01	29.52	30.63	28.89	0.960
#12	1.68	9.96	9.33	9.47	8.96	8.50	10.06	9.38	0.542
#13	1.52	3.22	3.06	3.15	2.86	2.49	2.72	2.92	0.253
#14	1.41	7.10	6.67	6.98	6.36	6.96	6.63	6.78	0.256
#15	1.30	1.57	1.36	1.42	1.49	1.59	1.57	1.50	0.085
#16	1.19	2.84	2.42	2.76	2.11	2.28	1.81	2.37	0.355
#18	1.00	4.81	4.02	4.39	3.21	3.80	3.23	3.91	0.580
#20	0.84	3.38	2.51	3.10	1.80	2.60	1.64	2.50	0.628
#25	0.71	2.84	2.32	2.44	1.40	2.22	1.36	2.10	0.542
#30	0.59	2.48	1.69	2.03	0.96	1.62	0.96	1.63	0.548
#35	0.50	0.76	0.56	0.74	0.24	0.64	0.27	0.54	0.210
#40	0.42	0.62	0.46	0.53	0.13	0.44	0.15	0.39	0.186
#50	0.30	0.82	0.75	0.73	0.25	0.69	0.25	0.58	0.239
Pan	0.00	0.57	0.55	0.52	0.20	0.46	0.26	0.43	0.145
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		31.03	26.37	28.79	21.00	25.81	20.86	25.64	4.100

TABLE XII (Continued)

Roller Mill, Gap :0.5 mm
Temp.:35 C

Temp.:35 C
Gap :0.5 mm

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.06	0.04	0.07	0.03	0.11	0.04	0.06	0.027
#8	2.38	7.55	8.20	6.81	8.70	8.18	7.37	7.80	0.624
#10	2.00	41.16	37.76	38.64	39.40	40.29	39.42	39.44	1.091
#11	1.85	35.54	37.22	36.67	37.04	36.64	38.18	36.88	0.788
#12	1.68	10.01	10.81	11.88	9.25	9.59	9.50	10.17	0.914
#13	1.52	2.37	2.28	2.38	1.73	2.19	2.04	2.17	0.227
#14	1.41	2.08	2.46	2.22	2.50	1.91	2.10	2.21	0.211
#15	1.30	0.13	0.16	0.15	0.14	0.12	0.14	0.14	0.013
#16	1.19	0.18	0.20	0.19	0.15	0.22	0.21	0.19	0.023
#18	1.00	0.25	0.22	0.26	0.29	0.20	0.30	0.25	0.035
#20	0.84	0.19	0.18	0.19	0.20	0.13	0.13	0.17	0.029
#25	0.71	0.14	0.17	0.18	0.21	0.12	0.17	0.17	0.029
#30	0.59	0.16	0.15	0.17	0.17	0.16	0.15	0.16	0.008
#35	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.17	0.14	0.18	0.20	0.15	0.24	0.18	0.033
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		5.68	5.97	5.93	5.59	5.20	5.49	5.64	0.290

TABLE XII (Continued)

Roller Mill, Gap :0.7 mm
Temp.:5 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.05	0.08	0.07	0.06	0.03	0.03	0.05	0.019
#8	2.38	6.81	6.55	5.96	6.10	6.47	6.14	6.34	0.297
#10	2.00	37.89	37.20	34.79	36.39	36.24	35.09	36.27	1.089
#11	1.85	37.41	36.51	37.15	36.22	35.98	36.58	36.64	0.499
#12	1.68	9.63	10.56	10.86	10.32	10.10	10.40	10.31	0.384
#13	1.52	2.78	2.69	2.22	2.62	2.52	2.69	2.59	0.182
#14	1.41	3.31	3.16	4.49	3.62	3.84	4.29	3.79	0.482
#15	1.30	0.38	0.47	0.55	0.50	0.61	0.67	0.53	0.094
#16	1.19	0.45	0.67	0.78	0.78	0.73	0.69	0.68	0.112
#18	1.00	0.36	0.65	0.93	0.91	0.90	0.90	0.78	0.208
#20	0.84	0.31	0.45	0.59	0.62	0.66	0.63	0.54	0.124
#25	0.71	0.27	0.35	0.58	0.37	0.57	0.63	0.46	0.136
#30	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#35	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.34	0.65	1.03	1.50	1.34	1.27	1.02	0.407
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		8.20	9.10	11.17	10.91	11.17	11.77	10.39	1.400

TABLE XII (Continued)

Roller Mill, Gap :0.7 mm
Temp.:20 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#8	2.38	8.20	8.82	8.54	7.24	7.57	6.96	7.89	0.678
#10	2.00	38.26	39.43	38.59	36.65	34.70	35.34	37.16	1.732
#11	1.85	31.38	31.89	32.97	33.36	33.71	33.52	32.80	0.869
#12	1.68	9.11	9.48	10.36	10.32	10.30	10.17	9.96	0.485
#13	1.52	2.51	2.21	2.25	2.46	2.82	2.74	2.50	0.228
#14	1.41	4.18	4.07	3.59	4.33	4.10	4.19	4.08	0.234
#15	1.30	0.90	0.78	0.77	0.77	0.99	0.89	0.85	0.083
#16	1.19	0.87	0.78	0.77	1.05	1.04	1.09	0.94	0.132
#18	1.00	1.43	1.06	0.91	1.27	1.54	1.54	1.29	0.238
#20	0.84	0.84	0.54	0.52	0.84	1.08	1.02	0.81	0.214
#25	0.71	0.85	0.42	0.33	0.71	0.94	0.80	0.68	0.224
#30	0.59	0.62	0.26	0.19	0.47	0.61	0.69	0.47	0.188
#35	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.87	0.26	0.21	0.53	0.59	1.04	0.58	0.299
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		13.06	10.39	9.55	12.44	13.72	14.01	12.20	1.830

TABLE XII (Continued)

Roller Mill, Gap :0.7 mm
Temp.:35 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#8	2.38	6.89	7.73	7.37	7.52	7.32	6.42	7.21	0.435
#10	2.00	38.15	36.42	38.22	38.55	36.24	37.52	37.52	0.896
#11	1.85	36.51	36.84	36.70	36.38	38.53	38.05	37.17	0.816
#12	1.68	10.91	11.04	10.16	10.47	10.92	9.61	10.52	0.506
#13	1.52	2.85	2.62	2.49	2.40	2.34	2.12	2.47	0.226
#14	1.41	2.60	2.80	2.71	2.69	2.93	3.46	2.87	0.286
#15	1.30	0.35	0.44	0.43	0.39	0.36	0.38	0.39	0.034
#16	1.19	0.39	0.43	0.38	0.31	0.34	0.60	0.41	0.093
#18	1.00	0.55	0.54	0.47	0.45	0.40	0.53	0.49	0.055
#20	0.84	0.27	0.31	0.28	0.26	0.22	0.31	0.28	0.031
#25	0.71	0.21	0.30	0.26	0.23	0.17	0.32	0.25	0.051
#30	0.59	0.18	0.23	0.26	0.16	0.11	0.32	0.21	0.069
#35	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.12	0.28	0.24	0.18	0.12	0.36	0.22	0.087
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		7.53	7.97	7.54	7.08	7.00	8.41	7.59	0.530

TABLE XII (Continued)

Hammer Mill, Feed Rate: 17 kg/min
Temp.:20 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
#8	2.38	1.49	1.54	1.82	1.59	1.75	1.72	1.65	0.119
#10	2.00	15.47	15.49	15.92	14.76	15.07	15.13	15.31	0.371
#11	1.85	19.07	19.53	19.83	19.69	19.28	21.95	19.89	0.955
#12	1.68	8.24	6.94	6.54	7.77	6.99	6.58	7.18	0.624
#13	1.52	2.40	2.09	1.95	2.60	2.02	2.71	2.29	0.292
#14	1.41	11.36	11.74	10.73	10.74	10.83	11.25	11.11	0.373
#15	1.30	3.89	4.45	3.77	3.81	3.89	4.11	3.99	0.231
#16	1.19	7.36	6.94	7.13	7.32	7.37	6.74	7.14	0.237
#18	1.00	9.22	9.17	9.49	9.41	9.60	9.47	9.40	0.151
#20	0.84	5.13	5.71	5.69	5.63	5.59	5.38	5.52	0.205
#25	0.71	6.07	5.34	5.74	5.52	5.87	5.38	5.66	0.264
#30	0.59	4.56	5.20	5.02	5.23	5.50	4.60	5.02	0.342
#35	0.50	2.03	1.92	2.05	2.04	2.10	1.69	1.97	0.136
#40	0.42	1.04	1.08	1.16	1.15	1.17	0.96	1.09	0.076
#50	0.30	1.34	1.38	1.54	1.35	1.43	1.14	1.37	0.122
Pan	0.00	1.33	1.50	1.61	1.39	1.52	1.20	1.43	0.137
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		55.74	56.51	55.90	56.20	56.90	54.62	55.98	0.790

TABLE XII (Continued)

Hammer Mill, Feed Rate:29 kg/min.
Temp.:20 C

sieve No.	sieve opening size (mm)	fraction on each sieve by weight (%) 1	2	3	4	5	6	mean (%)	Std (%)
#7	2.83	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.007
#8	2.38	3.04	3.10	3.30	3.50	3.03	3.21	3.20	0.165
#10	2.00	26.60	26.20	26.30	28.69	25.82	24.43	26.34	1.258
#11	1.85	30.15	30.20	31.02	31.90	30.80	30.35	30.74	0.611
#12	1.68	9.39	10.33	9.58	9.62	9.71	9.91	9.76	0.298
#13	1.52	2.30	2.37	2.42	2.36	2.81	2.45	2.45	0.167
#14	1.41	6.42	6.24	6.20	6.26	5.87	6.31	6.22	0.169
#15	1.30	1.94	1.87	1.91	1.92	1.75	1.95	1.89	0.068
#16	1.19	2.95	2.90	2.79	2.71	2.83	3.04	2.87	0.108
#18	1.00	4.64	4.64	4.70	4.12	4.50	4.71	4.55	0.206
#20	0.84	2.54	2.38	2.27	1.97	2.56	2.71	2.41	0.241
#25	0.71	2.63	2.85	2.86	2.33	2.85	3.05	2.76	0.228
#30	0.59	2.84	2.65	2.51	1.88	2.86	3.18	2.65	0.404
#35	0.50	1.28	1.22	1.18	0.85	1.34	1.35	1.20	0.169
#40	0.42	0.84	0.77	0.70	0.52	0.83	0.87	0.76	0.119
#50	0.30	1.21	1.13	1.09	0.65	1.22	1.19	1.08	0.198
Pan	0.00	1.24	1.14	1.17	0.74	1.20	1.28	1.13	0.180
sum		100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		30.82	30.16	29.80	26.29	30.63	32.10	29.97	1.960

TABLE XII (Continued)

Whole mustard seed used
for roller milling

sieve No.	sieve opening size (mm)	weight on each sieve (gram) 1	2	3	mean (gram)	Std (gram)
#7	2.83	0.00	0.00	0.00	0.00	0.000
#8	2.38	4.73	5.19	5.52	5.14	0.325
#10	2.00	37.62	38.58	39.01	38.40	0.578
#11	1.85	41.80	41.63	39.30	40.91	1.141
#12	1.68	12.12	10.63	12.24	11.66	0.735
#13	1.52	2.05	2.28	2.29	2.21	0.109
#14	1.41	1.64	1.68	1.62	1.65	0.026
#15	1.30	0.04	0.02	0.02	0.03	0.009
#16	1.19	0.00	0.00	0.00	0.00	0.000
#18	1.00	0.00	0.00	0.00	0.00	0.000
#20	0.84	0.00	0.00	0.00	0.00	0.000
#25	0.71	0.00	0.00	0.00	0.00	0.000
#30	0.59	0.00	0.00	0.00	0.00	0.000
#35	0.50	0.00	0.00	0.00	0.00	0.000
#40	0.42	0.00	0.00	0.00	0.00	0.000
#50	0.30	0.00	0.00	0.00	0.00	0.000
Pan	0.00	0.00	0.00	0.00	0.00	0.000
sum		100.00	100.00	100.00	100.00	0.000
partial sum (#13-pan)		3.74	3.98	3.93	3.88	0.130

VITA

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